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# (54) CUSTOM ORTHODONTIC APPLIANCE FORMING METHOD AND APPARATUS

VERFAHREN UND VORRICHTUNG ZUM HERSTELLEN VON INDIVIDUELL ANGEPASSTENORTHODONTISCHEN EINRICHTUNGEN

PROCEDE ET APPAREIL DE FORMATION D'APPAREILS ORTHODONDIQUES PERSONNALISES

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## Description

[0001] The present invention relates to the design, manufacture and use of orthodontic appliances for the straightening of teeth, and more particularly, to the automated design, manufacture and use of custom orthodontic appliances based on individual patient anatomy and to the diagnosis of patients therefor and the treatment of patients therewith.

[0002] The orthodontic treatment of patients has as its fundamental objective the repositioning or realignment of the teeth of a patient in the patient's mouth to positions where they function optimally together and occupy relative locations and orientations that define a pair of opposed and cooperating planar, or nearly planar, smooth arches. The teeth of the two arches, the maxillary arch of the teeth of the upper jaw and the mandibular arch of the teeth of the lower jaw, when in an optimal or ideal position, contact the teeth of the opposite arch along a surface that is usually flat or slightly upwardly concave and commonly referred to as the plane of occlusion.

[0003] The treatment applied to patients who have been diagnosed as having teeth insufficiently close to the ideal positions to require orthodontic correction includes an initial or rough procedure to overcome the more serious defects of tooth positioning followed by a finish treatment designed to bring the teeth as closely as possible or practical to their ideal positions. The rough treatment usually involves the movement of certain teeth through the use of any of a number of recognized techniques performed by an orthodontia, and sometimes procedures such as the extraction of certain teeth or surgery on the patient's jaw performed by an oral surgeon.

[0004] In the finish treatment, the orthodontia applies an appliance, or set of braces, to the teeth of the patient to exert continual forces on the teeth of the patient to gradually urge them toward their ideal positions. The application of the appliance usually involves the attachment of brackets to the teeth, either with the application of adhesive to the teeth or the securing of bands around the teeth. The brackets are usually each provided with a slot through which an archwire is extended. One archwire is provided for the upper teeth and one for the lower teeth. Typically, the slots in the brackets are of rectangular cross-section and the archwire is of rectangular cross-section. The archwire installed in the slots of the brackets interconnects the teeth, through the brackets, and exerts forces on the teeth to translate or rotate them toward a finish position envisioned by the orthodontist.

[0005] It has been recognized in the design and application of orthodontic appliances that an ideally designed and installed orthodontic appliance will present the slots of the brackets in a position to initially receive a preshaped archwire that will elastically deform to exert corrective forces on the teeth to urge them toward their finish positions. When in their finish positions, the archwire of the ideally designed appliance will no longer be elastically deformed, and will no longer exert forces upon the teeth. Achieving this objective has been inhibited by certain problems in the prior art.

[0006] One problem presented by the prior art is that current orthodontic products are designed and manufactured to average anatomy. As a result, orthodontists are faced with the need to select what they perceive to be the brackets and archwires of the closest design to those required by a particular patient, and to modify the designs for treatment of the patient. Some of this modification may be performed when the appliance is initially installed, but almost inevitably modification is required during the course of treatment of the patient. This modification may take the form of the replacement of brackets, but most commonly requires a periodic bending and reshaping of the archwire as the treatment progresses. Thus, the treatment of the patient has become a manual feedback system in which the orthodontist monitors the progress of the patient's treatment and then readjusts the appliance, usually by bending the archwires, to correct the forces being applied to the teeth to bring the teeth to their ultimate positions, which are less than ideal. As a result, the patient may be subjected to treatment over a period that is longer than would be necessary if the appliance were initially made to the optimum design. In addition, the time required of the orthodontist for implementation of the treatment may be several times greater than it would be if modification of the appliance were unnecessary. Thus, the orthodontist is able to treat fewer patients and the cost of the treatment to the patient or so the orthodontist is increased.

[0007] Location of the connection points for the appliance to the teeth also presents a problem in the prior art. Typically, brackets are bonded to the teeth and then interconnected by the installation of the archwires. This is done when the teeth are in their maloccluded positions, with the orthodontist having only a mental vision of where the finish positions of the teeth will be and where the brackets are to be placed to move the teeth so those finish positions. For more effective use of the appliance and to promote ease in cleaning the teeth, the orthodontist prefers to locate the brackets and archwires away from the gums. If they are placed to close to the tips of the teeth, however, they may interfere with the teeth of the opposite arch as the teeth approach their finish positions.

[0008] Another problem of the prior art that has inhibited the selection or design of an ideal orthodontic appliance for the patient is the difficulty in arriving at an expression of the ideal finish position of the teeth. Orthodontists typically make models of the patient's mouth and, with the models and the aid of x-rays, determine a treatment so move the teeth so finish tooth positions. This process is time consuming and presents a source of error and inaccuracy. From the measurements and based on the judgment of the orthodontist, appliance components are selected so implement the prescribed treatment. In reality, the treatment of patients is in many eases more of an art than a science, with results ranging from poor to excellent, and generally variable.

[0009] The need for custom manufactured orthodontic appliances and the use of automatic design techniques has

been recognized by some, while others have advocated adherence to standard components and manual techniques in view of a perceived lack of practical custom appliance manufacturing and automated appliance design systems of the art.

[0010] E-P-A 0502227 describes a method of forming an orthodontic brace in which a model of a patient's teeth is used to determine the contours thereof and from this, and desired teeth positionings provided by the orthodontist, an appropriate bracket geometry is determined. In determining it, mesio-distal profiles of the teeth are employed, these being two-dimensional representations of individual tooth shapes, the profiles being related to the position of the arch-wire. The geometry is computed such that the arch wire, when positioned on the brackets, has a substantially linear configuration in a vertical plane and a progressive curvature in a horizontal plane. The computed geometry is then employed automatically to form the brackets which, with the arch wire, are shipped to the orthodontist for fitting.

[0011] WO90/08512 also discloses a method of orthodontic appliance design involving digitization of teeth shape and calculation of desired bracket geometry. In this case the finish position is calculated with respect to the initial position in a mathematical model produced by a CAD system from the digitized information. The orthodontist provides a description of the desired results and account is taken of the patient's physical characteristics. A standard bracket is then modified to provide for the determined necessary tooth movements. As a CAD system is employed, it would seem that an operator calculates the final positions by manipulation of the model displayed as an image.

[0012] The development of automated custom appliance design systems has encountered several difficulties. These difficulties have included the task of developing an automated system that includes reliable and efficient decision making algorithms and techniques for automatically determining an ideal finish position of the teeth. Further, these difficulties have included arriving at an expression of appliance geometry in terms that can be efficiently produced by automated appliance manufacturing equipment. Furthermore, the prior art has not provided a way to accurately manufacture an appliance on an individualized basis in accordance with the appliance design. An additional problem in the automated design and manufacture of orthodontic appliances lies in the difficulty in designing the custom design system to take into account the professionally recognized parameters and criteria, derived over many years from the knowledge and experience of the practicing and clinical orthodontist, upon which diagnosis and treatment is based.

[0013] Accordingly, there is a great need in orthodontics for a practical, reliable and efficient custom appliance automated design and manufacturing system, and method of providing custom appliances and treating patients therewith.

[0014] A primary objective of the present invention is to provide a practical, reliable and efficient custom appliance automated design and manufacturing system and methods of automatically designing custom orthodontic appliances and treating patients therewith.

[0015] It is a particular objective of the present invention to provide an automated custom orthodontic appliance design and manufacturing system that can be easily and reliably used by practicing orthodontists and that will make best use of the skills, knowledge and experience that the orthodontist possesses. It is a further objective of the present invention to increase the accuracy of the orthodontist's treatment, to render the use of the orthodontist's time more efficient, to eliminate sources of error and guesswork from the orthodontist's treatment of patients, and to efficiently, repeatedly and reliably perform automatically the many of the routine steps in the diagnosis, prescription and implementation of orthodontic treatment and in the design and manufacture of orthodontic appliances.

[0016] It is a further objective of the present invention so improve the practice of orthodontics by aiding the practitioner in achieving optimal finish treatment of patients and in more accurately determining and precisely achieving the finish placement of a patient's teeth. An additional objective of the present invention is to provide for the accumulation of data from individual patients for the analysis of the data so advance the orthodontic art.

[0017] It is still another objective of the present invention so apportion the tasks involved in the design and manufacture of custom appliances most efficiently between orthodontist and appliance manufacturing facility in accordance with the scale and other particulars of the individual practitioner operation.

[0018] A method of fabricating a custom orthodontic appliance to position teeth of a patient to preferred finish positions in the mouth of the patient, in accordance with the invention, comprises the steps of measuring anatomical shapes from the mouth of the patient, and producing therefrom digitized anatomical shape data including <u>three dimensional</u> tooth shape data representing the shapes of individual teeth of the patient; deriving an <u>ideal</u> dental archform by processing the digitized anatomical shape data with a digital computer programmed to produce a digitized mathematical archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical shape data <u>and</u> the digitized mathematical archform model to mesio-distally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth; designing a custom orthodontic appliance with the computer from the digitized three dimensional tooth shape data, the established appliance connection points and the derived tooth finish positions, such that the custom orthodontic appliance has an appliance configuration dimensioned to interconnect the teeth at their respective connection points with the teeth in the derived tooth finish positions; producing machine readable control signals containing geometric

information correlated to the results of the appliance designing step; and automatically fabricating a custom orthodontic appliance with a machine responsive to the machine readable control signals to shape the appliance according to the geometric information contained in the control signals so as to form the custom orthodontic appliance having the designed appliance configuration.

[0019] A custom orthodontic appliance fabricating apparatus, in accordance with the invention, comprises means for measuring anatomical shapes from the mouth of the patient and producing thereby digitized anatomical shape data including three dimensional tooth shape data representing the shapes of individual teeth of the patient, a digital computer including program means for deriving an ideal dental archform from the digitized data with a specially programmed digital computer to produce a digitized archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical data and the derived digitized ideal archform to mesio-distally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth designing, from the digitized tooth shape data, established appliance connection point and the derived tooth finish positions, an appliance configuration such that a custom appliance fabricated in accordance therewith is dimensioned to interconnect the teeth at the connection point with the teeth in the derived tooth finish positions, and producing machine code containing geometric information correlated to the designed appliance configuration; and a machine for automatically fabricating a custom orthodontic appliance in response to the machine code to shape the appliance, according to the geometric information so as to form the appliance with the designed appliance configuration.

[0020] The system and method depart from traditional design and manufacture by designing orthodontic appliances around the anatomy of the individual patient. Further, unlike current orthodontic products that are designed and manufactured to avenge anatomy, the orthodontic products of the present invention and the methods of manufacturing and using them are tailored to the individual anatomy of the patient.

[0021] These and other objectives and advantages of the present invention will be more readily apparent from the following detailed description of the drawings in which:

**Figs. 1-1F** are diagrams illustrating the preferred embodiments of the system of the present invention, of which:

**Fig. 1** is a block diagram illustrating one preferred embodiment of an automated system for the design and manufacture of custom orthodontic appliances for the treatment of patients therewith according to the principles of the present invention.

**Fig. 1A** is an elevational diagram of a video graphics image forming embodiment of the data input portion of one embodiment of the scanner of the system of **Fig. 1**.

**Fig. 1B** is an elevational diagram of a laser scanner version of a three dimensional graphics imaging embodiment of a scanner of the system of **Fig. 1**.

**Fig. 1C** is an elevational diagram of a mechanical tooth profile probe scanner version of a two dimensional imaging portion of one embodiment of the scanner of the system of **Fig. 1**.

**Fig. 1D** is an isometric diagram of one embodiment of a bracket cutting device of the system of **Fig. 1**.

**Fig. 1E** is an isometric diagram of one embodiment of a wire forming device of the system of **Fig. 1**.

**Fig. 1F** is an isometric diagram of a bracket placement jig forming device of the system of **Fig. 1**.

**Figs. 2-2D** are flow chart diagrams of the preferred methods of carrying out the present invention, of which:

**Fig. 2** is a flow chart of one preferred embodiment of the process of the present invention performed with the system of **Fig. 1**.

**Fig. 2A** is a more specific flow chart illustrating the steps of the input procedure of automated tooth positioning and appliance design and manufacturing operation of the process of **Fig. 2**.

**Fig. 2B** is a more specific flow chart illustrating the steps of the analysis and tooth finish position calculating procedure of the automated tooth positioning and appliance design and manufacturing operation of the process of **Fig. 2**.

**Fig. 2C** is a more specific flow chart illustrating the steps of the custom appliance design procedure of the automated appliance design and manufacturing operation of the process of **Fig. 2**.

**Fig. 2D** is a more specific flow chart illustrating the steps of the custom appliance manufacturing procedure of the automated tooth positioning and appliance design and manufacturing operation of the process of **Fig. 2**.

**Figs. 3-3C** are illustrations of graphics computer images produced in the input procedure, in which:

**Fig. 3** is an example of a computer display of a video image generated by the scanner of the system of **Fig. 1** illustrating in a top plan view a mandibular model produced by the scanner of the type shown in **Fig. 1A**.

**Fig. 3A** is an example of a portion of a three dimensional digital image, illustrated in perspective, and produced by the scanner of the type shown in **Fig. 1B**.

**Fig. 3B** is an illustration similar to **Fig. 3A** of another portion of a three dimensional digital image produced by the scanner of **Fig. 1B**.

Fig. 3C is an example of a set of vertical tooth profile images produced by the scanner of Fig. 1C.

Figs. 4-4E are plan views of the teeth of the patient on tooth placement archforms at various stages of the tooth position calculation procedure of Fig. 2B, of which:

Fig. 4 is a geometric diagram illustrating a horizontal plan view data input screen showing diagrammatically the video image of Fig. 3 used as a template, with variables relevant to the digitization of data from the mandibular video image marked thereon.

Fig. 4A is a geometric diagram similar to Fig. 4 for the maxillary teeth.

Fig. 4B is a geometric diagram plotting horizontal mandibular archforms calculated through the analysis procedure of Fig. 2B.

Fig. 4C is a geometric diagram plotting horizontal maxillary archforms calculated through the analysis procedure of Fig. 2B.

Fig. 4D is a horizontal plan diagram showing the maxillary teeth in their finish positions.

Fig. 4E is a horizontal plan diagram showing the mandibular teeth in their finish positions and with the custom appliance in place.

Figs. 5-5P are mathematical calculation diagrams for reference in connection with apline to circle conversion and tooth placement routines, in which:

Fig. 5 is a horizontal plan diagram illustrating the placement of a tooth on an archform equation described in circle segment form.

Figs. 5A-5J are detailed diagram of the spline to circle conversion and tooth placement subroutines.

Figs. 5K-5P are detailed diagrams of the tooth placement subroutine.

Figs. 6-6I are diagram of tooth profiles illustrating landmark determination, tooth inclination and vertical positioning, in which:

Fig. 6 is an isometric image of a three-dimensional computerized representation, similar to Fig. 3A, of a molar showing the locations of alternative vertical labial-lingual profile planes and tooth profiles.

Fig. 6A is a mathematical tooth profile plot as illustrated on the computer screen of the system of Fig. 1 of a mandibular molar showing selected landmark parameters.

Fig. 6B is a mathematical tooth profile plot, similar to Fig. 6A, of a mandibular cuspid or incisor showing selected landmark parameters.

Fig. 6C is a mathematical tooth profile plot, similar to Fig. 6A, of a maxillary molar or bicuspid showing selected landmark parameters.

Fig. 6D is a mathematical tooth profile plot, similar to Fig. 6A, of a maxillary cuspid or incisor showing selected landmark parameters relevant thereto.

Fig. 6E is representation of a display, similar to Fig. 3C, of an array of mathematical tooth profile plots of all of the teeth, angularly oriented, with landmark parameters marked thereon.

Fig. 6F is representation of a display of an array of mathematical tooth profile plots, similar to a portion of Fig. 6E, of the mandibular teeth with working horizontal placement planes marked thereon.

Fig. 6G is mathematical tooth profile plot, similar to Fig. 6A, of a mandibular posterior tooth with relevant dimensional variables for placement of the tooth marked thereon.

Fig. 6H is mathematical tooth profile plot, similar to Fig. 6B, of a mandibular anterior tooth with relevant dimensional variables for the placement of the tooth marked thereon.

Fig. 6I is mathematical tooth profile plot, similar to Fig. 6H, of the tallest mandibular tooth.

Figs. 7-7D are diagrams for reference in connection with the finish tooth position calculation, of which:

Fig. 7 is an elevational diagram of the relationship of the jaws of a patient for illustration of cuspid rise occlusion calculation.

Fig. 7A is an enlarged view of a portion of Fig. 7.

Fig. 7B is a plan mathematical diagram illustrating certain of the mathematics of tooth placement on the mandibular offset arch.

Fig. 7C is a perspective diagram illustrating the relationship of the vertical tooth profile planes and relevant horizontal arch planes in the course of tooth finish position calculation.

Fig. 7D is a set of related elevational profiles of mandibular and maxillary teeth showing occlusal and overlap relationships in the course of tooth finish position calculations.

Figs. 8-8H are diagrams for reference in connection with the steps of the custom appliance design procedure, of which:

Fig. 8 is a diagram similar to Fig. 7D illustrating archwire plane and bracket slot design on positioned teeth.

Fig. 8A is an elevational diagram illustrating a bracket and slot configuration in connection with the diagram of Fig. 8.

Fig. 8B is a top view illustrating the relation of a tooth to an archform by placement routine.

Fig. 8C is a tooth profile diagram illustrating the slot in-out dimension calculation.

Fig. 8D is a perspective diagram illustrating the placement of a custom bracket onto a tooth with the use of a custom placement jig.

Fig. 8E is a plan diagram of a custom archwire for the appliance required to move the mandibular teeth to the finish positions illustrated in Fig. 4E.

Fig. 8F is a plan diagram illustrating the labial installated appliance on the teeth of the patient in their initial positions.

Fig. 8G is a plan diagram, similar to Fig. 8F, illustrating a lingual appliance installed on the teeth of the patient.

Fig. 8H is an elevational diagram illustrating an orthodontic lingual bracket of the appliance of Fig. 8G.

Fig. 8I is a top view of a bracket having a base slot curvature conforming to that of an archwire supported therein.

Figs. 9-9W are diagrams relating to appliance manufacturing steps, of which:

Figs. 9-9H relate to substeps of the bracket slot cutting code generation and bracket manufacturing step.

Figs. 9I-9W relate to the substeps of the bracket placement jig manufacturing step.

[0022] The overall configuration of the system 10 is illustrated diagrammatically in Fig. 1. The overall operations of the preferred method of the invention are illustrated in the flowchart of Fig. 2, where examination of a patient is performed by an orthodontist at the orthodontist's office to assemble information to determine the patient's condition, prescribe the approrpriate treatment, and specify the type of orthodontic appliance to implement the treatment. The information is communicated to a remotely located appliance design and manufacturing facility where the design of a custom appliance for use in administering the treatment is carried out with the use of computer analysis. The appliance design, together with the information necessary for the orthodontist to install the appliance on the patient is then transmitted back to the orthodontist, who installs the appliance and administers the treatment in accordance with the appliance manufactures instructions and his own professional expertise.

SYSTEM CONFIGURATION

[0023] Referring to the system diagram of Fig. 1, an orthodontic appliance manufacturing and patient treatment system 10 is illustrated. The system components are distributed between two locations, a doctor's office 11, and an appliance design and manufacturing facility 13. At the doctor's office 11, a patient 12, who requires orthodontic treatment, is examined by an orthodontist 14, who makes a diagnosis 15 of the condition of the patient and of the treatment, if any, needed. The examination involves the traditional application of the skill, knowledge and expertise of the orthodontist 14, and results in the preparation of detailed records 16 of the anatomy and condition of the mouth 18 of the patient, of the treatment proposed, and of other information necessary to the preparation of an orthodontic appliance.

[0024] The records 16 prepared by the orthodontist include a physical modal 20 from a mold of the patient's mouth 18, which includes a mandibular model 21 of the patients lower jaw or mandible 22 and a maxillary model 23 of the patient's upper jaw or maxilla 24. The records 16 also include prescription 27 wherein the orthodontist sets forth a treatment to be applied to the patient and a result to be achieved by the treatment. The prescription 27 may also include a specification of techniques that are to be included in the treatment and a designation of an orthodontic appliance to be employed. The records 16 will further include identification information 17 and patient history information 19.

[0025] In the illustrated embodiment of the invention, the records 16 are transmitted to the appliance manufacturing facility 13, at which the finish position of the teeth are calculated and a custom appliance 25 is designed and manufactured. The facility 13 is provided with one or more trained operators 28. In some embodiments, the physical model 20 itself is transmitted in the information 16 to the facility 13. In such cases, one of the primary functions of the operators 28 is to input digital information 26 from the records 16 into a computer 30a. Another function is to operate the same or another computer 30b to design the custom appliance 25, and to operate NC equipment 38 controlled by one of the same or another computer 30c to manufacture the appliance 25. Where the inputing, design and manufacture are performed at the appliance facility 13, the computers 30a, 30b and 30c may be the same computer 30.

[0026] In other embodiments of the invention, the orthodontist 14 digitizes data from the model 20, in which case the inputing computer 30 is located at the orthodontist's office 11. In these embodiments, the digitized information 26, rather than the physical model 20, is transmitted to the appliance facility 13. The analyzing and appliance design computer is nonetheless preferably at the appliance facility 13.

[0027] The entry of the information into the input computer 30 involves a digitizing of the information 16 to produce the digitized anatomical information 26 in machine readable form for analysis by the analyzing computer 30b. The input computer 30 connected thereto by a scanner 33, which, in the alternative embodiments of the invention, includes equipment that employs one or more video cameras, mechanical probes, laser scanners, ultrasonic scanners, moire image scanners or other forms of imaging or measurement hardware that alone, or in combination with other such components, produce anatomical geometric information that describes the patient's teeth and jaw. The images may be three-dimensional or be made along a plurality of planes or other surfaces that can ultimately be combined to provide information in three dimensions.

[0028] The combined information from the scanner 33 of the illustrated embodiment provides a basis for three dimensional analysis of the patient's teeth and from which calculations of finish tooth positions can be made. From the final positional calculations and tooth anatomy data, automatic design and manufacture of the custom orthodontic appliance 25 is carried out. In the illustrated embodiment, the data is imaged in a plurality of differently oriented two dimensional planes in the computer 30, then mathematically manipulated and combined in the computer 30b to construct a three dimensional solution to the tooth positioning and appliance design problems.

[0029] In a configuration in which the scanner 33 is connected to a separate dedicated inputing computer 30 is herein described, the functional equivalent of the inputing computer 30 may be included in circuitry within the scanner 33 itself.

[0030] Preferably, the digital input process utilizes interactive methods by which an operator 28 uses a pointing device and digitizer to select particularly useful orthodontic parameters from graphics images produced by the scanner 33 on a screen 35 of a display connected to the inputing computer 30.

[0031] In embodiments where some or all of the extraction of the digitized anatomical information 26 from the model 20, which my also be derived directly from the mouth 18 of the patient 12, is accomplished by the orthodontist 14 at the orthodontist's office 11, the information 26 is digitized by the orthodontist 14 then transmitted as part of the information 16 to the appliance design center 13. The transmitted information 16 is preferably transmitted from the orthodontist's office 11 to the appliance facility 13 by modem, but may be transmitted in any other available manner.

[0032] An analysis and design computer 30b, preferably at the appliance design facility 13, produces an archive diskette 34 that is formatted and written with all of the relevant information of the analysis and the history and prescribed treatment of the patient 14.

[0033] The computer 30b at the appliance facility 13 calculates, based on the digitized information 26, the final position of the patients teeth, and the configuration of the appliance 25 required to move the patient's teeth to this final or finish position. As a result, calculated information for the patient is stored in a patient data file 36. From the calculations the computer 30c produces CNC machine readable code 42 for operating NC manufacturing equipment 38 to produce the appliance 25. An instruction document or file 37 is also produced, either by the computer 30b or the computer 30c, of information to aid the orthodontist 14 in creating the patient 14 with the custom appliance 25.

[0034] The manufacturing equipment 38 includes an appliance bracket cutting or forming machine 39 which produces custom brackets for the appliance 25 by cutting slots calculated angles and to calculated depths in slotless generic brackets. The machine 39 may also or alternatively shape the surfaces of the bracket bases. This provides the bracket design option of torquing the teeth by either the bracket slot or base, as may be best for various bracket materials.

[0035] The equipment 38 also includes an appliance archwire bending or forming machine 40 which produces custom shaped archwires for the appliance 25 by feeding and bending wire of any one of several available materials and stiffnesses into the custom archwire shape. The equipment 38 may also include a machine for forming patient treatment components and hardware to aid in the manufacture or installation of the appliance 25. In the illustrated embodiment, this includes a machine 41 for the making of bracket placement jigs, which cuts each tooth crown portion of the tooth profile into a plastic form, along with a superimposed cutout of the positioned bracket, for use in accurately installing the custom brackets in their calculated positions on the teeth.

[0036] The appliance manufacturing machines 38 may be connected directly to the analyzing computer 30b or one or more my be connected to a separate manufacturing equipment controlling computer or machine controller 30c. The computer 30c may be located at the appliance facility 13 or, together with one or more of the appliance manufacturing machines 38, 40 or 41, be located at the orthodontist's office 11. In one preferred embodiment of the invention, one manufacturing computer 30c and the bracket cutting machine 40 arc located at the orthodontist's office, along with the scanner 33 and input computer 30, which may be the same computer as the manufacturing computer 30c, while another manufacturing central computer 30c, which may be the analyzing computer 30b, the wire beading machine 40 and the jig forming machine 41 are located at the appliance facility 13. The optimum distribution of the computers 30, 30b and 30c and the scanner 33 and appliance manufacturing machines 38, 40 and 41 will be determined by the scale of the orthodontist's practice and the orthodontist's preferences. In the illustrated embodiment, the computers 30-30c are IBM PC clones, with Intel 80386 or 80486 microprocessors and equipped with 80387 or 80487 math coprocessors, respectively.

[0037] Certain components of the system 10 of Fig. 1 are described below in further detail.

<u>Scanning Assembly 33</u>

[0038] Three steps in the information input procedure (82), described below, involve the inputing into the computer 30, for analysis in digital form, of data concerning the shape of the mouth 18 of the patient 12 and of the shapes of the individual teeth therein. In these steps, digitized images and measurement data of the mouth 18 of the patient 12, preferably taken indirectly from the model 20, are digitized to form a three dimensional mathematical model of the patient's mouth 18. The mathematical model includes, in the preferred embodiment of the invention, the definition of certain parameters of the patient's lower jaw and individual teeth, and my include come information of the initial position and

orientation of the teeth in the mouth 18 of the patient 12 for evaluating the magnitude of the treatment.

**[0039]** The input information 26 is, in some embodiments of the invention, input as a full three dimensional image, and then simplified by reducing it to a plurality of curves in a plurality of differently oriented planes or fairly flat curved surfaces, each defined in the independent *X-Y* coordinate system of the respective surface or plane. In subsequent analysis, these planes are oriented, translated and rescaled with respect to each other in arriving at a derivation of the ideal finish positions of the teeth and the design of the custom appliance 25. In accordance with the preferred embodiment of the invention, curves and points on the contours of the jaw and teeth of the patient 12 are expressed in terms of accepted or generally applicable orthodontic parameters so that manual and automated decision making can combine and coordinate the best of orthodontic knowledge and experience with the efficiency and precision of computer analysis to minimize the use of the orthodontist's time, shorten the patient's treatment period and optimize the final treatment result.

**[0040]** The various types of and components of the scanner 33 of various embodiments of the invention are described below.

*Video Scanning Data Input Assembly 43:*

**[0041]** One preferred form or component of the scanner 33 includes a video imaging assembly 43 as illustrated in **Fig. 1A**. The video imaging assembly 43 includes one or more video cameras 44 which each produce two dimensional images of the patient's mouth 18, preferably by forming an image of the model 20. When two or more are used together, the video assembly 43 produces stereo images capable of being resolved in three dimensions. In the illustrated embodiment of the invention, a single video camera 44 is employed to produce two dimensional video images of a plan view of the patient's lower or upper jaws 22 and 24, from the models 21 or 23, respectively, in generally horizontal *X-Y* planes. In accordance with this embodiment, other forms or components of the scanner 33 are preferably employed to produce information in a third dimension as described below.

**[0042]** Referring to **Fig. 1A**, the video imaging assembly 43 is shown diagrammatically in side elevation at the appliance manufacturer's facility 13. The video imaging assembly 43, in its preferred form, is an operator-computer graphical interface that includes the video camera 44 connected to a video interface board 44a in the input computer 30. The camera 44 is mounted on a stand 45 to face downwardly to form a top plan view of one of the halves 21 or 23 of the model 20, shown as the mandibular portion 21 in **Fig. 3**, on a horizontal support 46 attached to a base 45a of the stand 45. The model half 21 or 23 is positioned on the support 46 such that the teeth face upwardly toward the camera 44 and so that the tips thereof lie generally in a horizontal plane that is maintained at a known fixed distance from the camera 44, so that the scale of the image formed by the camera 44 is known. This may be accomplished by mounting the support 46 on springs 46a to urge the model half 21 or 23 upwardly against a transparent horizontal plate 45b.

**[0043]** The input computer 30 has connected thereto a pointing device which may be a mouse 47a or, as shown, a mouse equipped digitizer board 47. The camera 44 produces a graphics image display 48 on the screen 35 of the computer 30, which an operator 28 may align with the assistance of a positioning grid *G* (**Fig. 4A**). With the digitizer 47, the operator selects points by positioning a cursor 48a on the screen 35 with the mouse 47a. The selection results in the storage of *X,Y* coordinate data for each of the points selected. The points selected, in the description of the preferred process below, correspond to preselected boundary points of the teeth and, from the mandibular model 21, the lower jaw. From these top view boundary points. tooth and mandibular jaw dimensions are calculated. The calculated dimensions are used in analysis steps to calculate equations for the mandibular bone structure or mandibular trough *MT* and to calculate from the trough equation and the calculated horizontal dimensions and relative positions of features on individual teeth the finish positions of the teeth.

**[0044]** In the alternative to selecting points from the video image display 48, the same points may be selected in the same manner from a plan view video image of a digitized three-dimensional computerized image of the teeth and jaws, such as an image formed by a laser scanner, moire interference pattern scanner, ultrasonic scanner, stereo video cameras, or other three-dimensional imaging apparatus. Sectional displays 55a and 55b of such a three-dimensional computerized image made with a laser scanner are shown in perspective in **Figs. 3A and 3B**, respectively. Such a laser scanner is described in connection with **Fig. 1B** below.

*Laser Three-dimensional Image Input Assembly 51:*

**[0045]** One preferred form or component of the scanner 33 is the laser generated three-dimensional image forming assembly 50 illustrated in **Fig. 1B**. Referring to **Fig. 1B**, one of the halves 21 and 23 of the model 20 is mounted on a support 51 while laser 52 directs a laser beam 52a onto the model 21 or 22. The laser beam 52a is reflected and the reflected beam is detected by a sensor 53 composed of a photoelectric pixel array which uses a triangulation method to convert a change in position on the sensor into a change in distance between the assembly 50 and the model 21 or 23 mounted to translate parallel to the model 21 or 23 on a support 54 so as to scan the model with the laser beam.

Equipment for producing images using laser technology in this manner is commercially available for forming computerized representations in three dimensions of manufactured and other objects. An example of equipment suitable for this purpose are the Cyber Scan™ Measurement System manufactured by Cyber Optics Corporation of Minneapolis, Minnesota. The images formed by such equipment would preferably include full detailed three-dimensional image data of the patient's lower and upper jaws 22 and 24, taken from the model 20, with the teeth in their original positions. The data is written in standard ASCII files by the equipment described and is readable by the input computer 30a into the digitized information files 26.

[0046] Illustrated in **Figs. 3A** and **3B** are two sections of the mandibular digitized model, and include a section 55a showing the front mandibular incisors $T_{BR1}$ and $T_{BL1}$ of the patient 12, and a section 55b showing the right mandibular second bicuspid $T_{BR5}$ and first molar $T_{BR6}$ of the patient 12. When such images are rotated to a horizontal plan view, a derivation of the same information that is available from the video imager 43 of **Fig. 1A** may be derived, and points may be selected therefrom for digitization automatically with software, or through an operator/computer interactive process as with the video scanner 43. The three-dimensional image 55 may be rotated into other orientations for the derivation of other information in various planes such as vertical tooth profile information that is derived with the mechanical scanner 57 described below. Additionally, other computerized procedures may be used to automatically derive information from the three dimensional image 55 with or without intervention or interaction by an operator.

*Mechanical Probe Digital Scanner Assembly 57:*

[0047] The scanner may also include, alternatively or in combination with other scanning equipment such as to video scanner assembly 43 of **Fig. 1A** or the laser scanning assembly of **Fig. 1B** above, a mechanical probe assembly 57 as illustrated in **Fig. 1C.** This entire assembly 57 is used in the illustrated embodiment of the invention in combination with the video scanner 43 to derive labial-lingual vertical profiles of the individual teeth of the patient from the model 20 to supplement jaw and horizontal tooth dimensional and shape information derived from a video image produced by the video scanner 43 from the model 20. Alternatively, portions of this assembly can be used to produce the same information from a three dimensional image 55 produced by equipment such an the laser scanning assembly 50.

[0048] Referring to **Fig. 1C**, the probe assembly 57 includes a measurement probe 60 which is moveable over the individual teeth of the model 21 to produce an electrical signal that is digitized for computer input of point locations or profiles of the surfaces of the teeth in separate *X-Y* for each tooth. In the illustrated embodiment of the process of the invention, to information 26 preferably derived from the model 21 includes the tooth profiles curves $PF_i$ in a labial-lingual plane viewed in a mesial-to-distal direction.

[0049] The probe assembly 57 further includes a magnetic base 59 upon which is mounted the model 20, and from which extends an upstanding vertical support 58 on which to probe 60 is mounted. The probe tip 60a is freely rotatable about a vertical axis on which its tip lies, while the probe itself is hooked to allow the tip to track recesses in the surfaces of the teeth of the model 21. The probe 60 is mounted on the support 58 to move in *X* and *Y* directions in a vertical plane preferably that extends through the support 58 and the probe 60. In this manner, the probe tip 60a is positioned to scan the surface of a tooth of the model 21 along this plan. The probe 60 is linked to to support 58 through a pair of orthogonal measurement position transducers 61, which respectively generate electrical analog measurements of the positions of the tip of the probe 60 along respective ones of the *X-Y* orthogonal coordinates. The outputs of the transducers 61 are connected to circuitry that generates a sequence of periodic readings of the transducer measurements of the probe tip positions which are then digitized. These outputs are sent in along lines 61a connected to input computer 30, preferably to a serial port thereof.

[0050] In use, a half of the model 20, for example, to mandibular model 21, is mounted upon the magnetic base 59 on a steel surveyors mount 62 which slides on the base 59 when lightly urged, but which otherwise holds its place thereon for precise positioning. The mount can be raised, lowered or tilted for positioning and for leveling. In operation, the probe 60 is manually moved by an operator 28 or automatically to scan the surface of each selected tooth of the model 21 to produce profile curves *PF* of a section of each tooth as illustrated in **Fig. 3C.** The profile *PF* may be generated by any one of a number of commercially available off-the-shelf CAD/CAM or illustration software packages, such as VERSACAD™ available from Prime Computers. Inc. of Bedford, Massachusetts. The video images 63 of the profiles *PF* are displayed on the screen 35 and the digitized profiles are stored as part of the input information 26 in non-volatile memory of the computer 30.

[0051] With the curves such as the profile *PF* so formed, an operator can, with the use of the pointing device 47, select, by positioning the cursor on the formed profile on the screen 35, point parameters of the tooth, the coordinates of which can be thereby input digitally into the computer 30.

*Appliance Manufacturing Equipment 38*

[0052] The manufacturing equipment 38 of the preferred embodiment of the invention includes: an appliance bracket

cutting or forming machine 39 that custom forms the bracket bases to mount to the teeth and cuts archwire slots in the brackets at precise calculated positions and angles; an appliance archwire bending or forming machine 40 that precisely bends archwires to a shape that will cooperate with the custom brackets to apply corrective forces to the teeth until they are in their calculated finish positions; and a bracket placement jig forming machine 41 that manufactures bracket placement jigs that conform to the contours of the patient's teeth, as recorded in the profiles *PF*. These jigs are used by the orthodontist to precisely place the custom brackets at calculated positions on the teeth.

**[0053]** The manufacturing equipment 38 is controlled by NC computer generated programs based on the data from the digitized input information files 26 and the calculated patient data riles 36.

*Bracket Cutting Machine 39:*

**[0054]** Referring to **Fig. 1D**, a bracket slot cutting machine 39 is illustrated. The machine 39 includes a stationary base 72 on which is fixed a pair of upwardly extending workpiece support brackets 72a to the top of which is pivotally mounted a workpiece or bracket support 73. On the support, a full set 80a of brackets 80 for the custom appliance 25 is mounted, prearranged in an assembly or cartridge of twenty or twenty-four brackets. The support 73 pivots about an axis 73a extending between the brackets 72a. Connected to the axis 73a is an angular positioning motor 74 which positions the support 73, and the brackets 80 mounted thereto, to any angular orientation with respect to the horizontal. The motor 74 has an input connected to the computer 30c to set the inclination to the slot inclination angle of the bracket design in response to NC command codes.

**[0055]** Also fixed to the base 72 and extending upwardly therefrom is a saw support bracket 72b. To the top of the support bracket 72b is a saw drive motor 75 and a set of three saw blade positioning linear drive actuator 76, including an X-drive actuator 76x. a Y drive actuator 76y, and a Z drive actuator 76z through which a saw support arm 77 is supported to move respectively in the X, Y and Z directions, that is, in an X direction horizontally perpendicular to the axis of rotation 73a of the bracket holder 73, in a Y direction horizontally parallel to the axis of rotation 73a of the workpiece holder 73, and in a vertical Z direction. The actuators 76 have inputs connected to the computer 30c to receive positioning signals from the computer 30c to cut arcuate slots in the X-Y plane of the machine 39 in response to NC commands generated in accordance with a custom appliance design.

**[0056]** At the remote end of the movable arm 77 is a slot cutter assembly 77a, drivably linked to the motor 75. The assembly 77a has extending downwardly therefrom a rotatable cutter blade drive shaft 77b, which has fixed to the lower end thereof a circular slot cutter blade 77c. The blade 77c lies in the horizontal X-Y plane and is of the thickness of the slot needed for the thickness of archwire selected. The archwires are typically rectangular in cross-section so that they are able to exert torque on the bracket, which accordingly will be provided by the saw blade 77c with a slot of rectangular cross-section. The base of the slot will be cut, in accordance with the command signals from the computer 30c, at an angle in the X-Y plane of the machine 39 that is tangent to the final curve of the archwire that it will receive. The base of the slot will be convex to accommodate the curve of the wire in the horizontal plane. The base of the slot will be convex to accommodate the curve of the wire in the horizontal plane. The inclination of the bracket slot is achieved by the angle of the support 73 in response to control signals from the computer 30c. The computer 30c is programmed to account for changes in elevation of the bracket 80 due to the offset of the brackets from the support axis of rotation 73a.

*Wire Reading Machine 40:*

**[0057]** The wire bending apparatus 40 is illustrated diagrammatically in **Fig. 1E**. Primary control of the apparatus 40 is preferably by an IBM PC clone, preferably with an 80386 or 80486 microprocessor with a math coprocessor, and with motion controller board 65 installed. The controller board 65 is, for example, an MC300 Motion controller 3-axis card manufactured by Motion Engineering, Inc. The MC300 is a dedicated motion control card which sends and received signals to and from MC-OLS stepper interfaces 66a and 66b. MC-OLS stepper motor interfaces 66a and 66b send control signal commands to the stepper motor power supplies 67a and 67b, such as Compumotor S-Drive stepper power supplies #88-011483D, regarding rate and direction of motion of the motors.

**[0058]** The power supply 67a has an output connected to wire feed rollers 68, positioned on opposite sides of a wire guide 68a, which guides archwire 69 to feed it from a continuous coil supply. The power supply 67b has an output connected to a wire bending roller assembly or wire anvil 70.

**[0059]** The controller 66b additionally is adapted to receive feedback signals regarding position from a disc encoder 70a, such as a Dynapar/Veeder Root #E1000A76500, which monitors the position of wire forming roller 70b, providing closed loop control of a wire bending roller 70b. The roller is driven by a wire anvil motor 70c, such as a Compumotor #S/SX 57-102, through a drive screw 70d, such as an Industrial Devices Corp. Electric cylinder #X995A-2-M56-MT1-200-PS. The screw 70d converts the angular position of the motor 70c into linear motion of the roller 70b to deflect and bend the wire 69 as it is fed through the guide 68a by the rollers 68.

**[0060]** By coordinating the anvil 70 and the wire feed 68, formed archwires 64 of any planar shape are fabricated. The

rollers 68 pinch the wire, forcing it to advance into the anvil 70. The roller 70b of the anvil 70 moves up and down varying the radius and thus controlling the radius to which the wire is permanently deformed. If the formation of archwires with inflection points, that is that have bends in opposite directions, a second anvil would be provided opposite the wire 69 from the anvil 70 and controlled in synchronism therewith.

[0061] A wire position sensor 71 is provided that inspects the finished archwire by comparing the width of the formed wire 64 to the desired width. The sensor 71 is mounted with respect to the anvil 70 and feed rollers 68 to detect the position of the formed archwire 64 when it is at the end of its forming cycle. This measurement provides a feedback signal that provides compensation for material property variations that effect the formed shape and the amount of overbending required. The sensor 71 sends information back to the computer 30c as to whether the wire 64 is acceptable or over-bent or under-bent. If the wire is either over or under-bent, the computer 30c calculates the correction required and incrementally modifies the signals through the interfaces 66a and 66b to provide compensation to progressively correct successive archwires 64 until the result of the signal from the sensor 71 is deemed acceptable by the computer 30c.

*Bracket Placement Jig Forming Machine 41:*

[0062] The bracket jig forming equipment 41 is preferably a standard NC mill configured as illustrated in **Fig. 1F**. The machine 41 includes the standard mill 81, having a downwardly projecting rotary tool head 81a on which is mounted an endmill tool 81b of, for example, 0.5 mm (0.020 inches) in diameter, where 0.55 mm (0.022 inch) archwire is used, and, for example 0.4 mm (0.016 inches) in diameter where 0.45 mm (0.018 inch) archwire is used.

[0063] The mill 81 is either connected to a controller which will have been loaded with CNC program code 42 prepared by the computer 30c or will be directly connected to the computer 30c. The mill 81 is provided with a tool support 81c to which a set of circular ABS plastic jig blanks 83, usually twenty or twenty-four in number, are fed by a feeding mechanism 81d, equipped with a magazine 81e of the sets 83a of jig blanks 83. The tool head 81a is moveable vertically to bring the tool 81b into contact with the blanks 83 and horizontally in the *X-Y* directions in accordance with the tool path instructions from the code 42.

## GENERAL OPERATIONS AND PROCEDURES

[0064] One preferred method of the invention is represented by the operations and procedures illustrated in the flowchart of **Figs. 2**.

[0065] The method preferably includes three general operations: (85) a patient evaluation operation performed by the orthodontist 14 at the doctor's office 11 on the patient 12; (87) a computer aided analysis and appliance design and manufacturing operation performed, preferably at least in part, at the appliance facility 13 to produce the custom appliance 25, and (89) a patient treatment operation that includes treatment of the patient 12 by the orthodontist 14 at the doctor's office 11 to install and use the appliance 25.

*(85) Patient Evaluation Operation*

[0066] Referring to the system diagram of **Fig. 1** and the flow chart of **Fig. 2**, the orthodontic evaluation operation (85) is performed at a doctor's office 11. The operation (85) includes the procedures (90) of the examination of a patient 12, (91) the preparation of the model 20 of the patient's mouth and teeth, (92) the prescription by the orthodontist 14 of treatment, (93) and communication to the appliance facility 13.

[0067] The examination procedure (90) the patient 12, who requires orthodontic treatment, is examined by an orthodontist 14, who makes a diagnosis 15 of the condition of the patient and of the treatment, if any, needed. Based on the diagnosis 15, the orthodontist or doctor 14 assembles the information 16 that is necessary to implement the prescribed treatment.

[0068] In assembling the information 16, the orthodontist 14 (91) prepares a model of the patient's mouth 18, usually a physical model 20 from a mold of the patient's mouth, in its initial condition at the time of the diagnosis 15. The model 20 includes the mandibular model 21 of the patient's lower jaw or mandible 22 and the maxillary model 23 of the patient's upper jaw or maxilla 24.

[0069] Then, further based on the diagnosis 15, the orthodontist 14 (92) prescribes a particular treatment and generates a prescription 27 in a tangible record form.

[0070] The orthodontist 14 then (93) communicates the information 16, for example, by transmitting the model 20, the prescription for treatment 27, a record of information 17 identifying the doctor 14 and the patient 12, together with information 19 containing statistical and historic data of the patient 12, to an appliance design facility 13, at some remote location. At the appliance design facility 13, the information 16 is digitized and input into the computer 30 for analysis.

[0071] Alternatively, the orthodontist 14 may convert the information 16 to digital computer readable form and transmit

the digitized information to the appliance design facility 13. In this alternative, the system 10 would be configured with the input computer 30 located at the orthodontist's office 11, and the orthodontist 14 or assisting personnel would perform portions of a data input procedure (94) described below.

*(87) Analysis, Design and Manufacture Operation*

[0072] When the information 16, which includes, for example, the model 20, the prescription 27 and the information 17 and 19, are received either at the appliance system manufacturer 13 or is ready to be digitized at the orthodontist's office 11, (87) an analysis, finish tooth position calculation, and orthodontic appliance design and manufacturing operation is begun. In the operation (87), the information 16 is processed and the custom appliance 25 for moving the patient's teeth to an optimum final or finish position in accordance with treatment prescribed by the orthodontist 14 is produced.

*(94) Input Procedure:*

[0073] In the input procedure (94) is illustrated in the flowchart of **Fig. 2A.** In the procedure (94), the received information 16 is input, in the illustrated embodiment by operator 28 at the design facility 13, into a computer 30 in digital form. Even where the inputing is performed by operator at the design facility 13, some information 16, such as the information 17 and 19, may be supplied by the orthodontist 14 in machine readable form and input directly into the computer 30. The input procedure (94) includes five steps (100)-(500). The steps of the input procedure (90), in the illustrated embodiment, also include certain substeps that are part of the function of the analysis step (92) but are more conveniently performed at the time of the information is entered into the computer.

[0074] The input steps (100) and (200) involve the entry of background information assembled by the orthodontist 14. In the input steps (300), (400) and (500), tooth and jaw positions and profiles are defined in terms of orthodontic parameters and landmarks that can be later analyzed by computer to best implement the orthodontic knowledge, skill and experience embodied in the prescription 27 and of the orthodontic profession while efficiently automatically producing a optimum result.

*(95) Analysis and Tooth Positioning Procedure:*

[0075] The computer analysis procedure is illustrated in the flowchart of **Fig. 2B.** In the computer analysis procedure (95), the digitized information input by the input procedure (94) is analyzed to calculate the finish position of the teeth, so that the custom appliance 25 can be designed in computerized design procedure (96) and manufactured in computer controlled manufacturing procedure (97). The analysis procedure (95) includes six steps and subroutines (600)-(1100). These steps include the following:

(600) The dental analysis step in which the orthodontic landmarks of the teeth are identified:
A minimum number of points on the tooth profiles are selected that are sufficient for determining the contact points between teeth that are relevant to finish tooth position calculation and appliance design.

(700) The cuspid rise determination step in which the occlusion of the upper and lower teeth is defined.

(800) The mandibular tooth placement step in which the plane of the mandibular teeth is defined and the teeth are positioned with respect to the mandibular trough, including the steps of placing the teeth with their crown long axes CLAs intersecting the plane of the mandibular trough on the mandibular trough equation MTE, adjusting the teeth vertically so the tips (except the cuspides) are in the same plane, calculating trigonometrically a horizontal OFFSET for each tooth from its crown height and long axis inclination angle LAI to define a mandibular trough offset equation MO, placing the teeth on the offset equation MO and moving the remaining teeth with their mesial contact points MCP in contact with the distal contact point DCP of the previous tooth.

(900) The best fit cusp step in which the best fit equation is derived for mandibular arch.

(1000) The mandibular teeth placement step in which the positions of the mandibular teeth are calculated for placement on the best fit arch equation.

(1100) The maxillary placement step in which the maxillary arch is derived for occlusion with the placed mandibular teeth.

[0076] Since the anterior teeth do not occlude incisal edge, to incisal edge, the best fit buccal cusp equation *BFBCE* is modified to take into account the distance from the *BFBCE* to the labial contact points of the mandibular incisors and laterals, plus a horizontal or labial clearance, with the maxillary teeth. This defines the points of occlusion with the maxillary anteriors, at the intersection of their lingual surfaces with the plane of occlusion *MOC*.

[0077] The vertical positioning of the maxillary anteriors and cuspids is then performed based on the vertical occlusion methods that have been prescribed, establishing an overlap for the incisors and cuspid rise as determined in step (700). This defines the incisal overlap or overbite.

[0078] Placement of the maxillary posterior teeth places the intersections of the marginal ridges and the central grooves from steps (400) to (600) the cusps of the mandibular teeth with which they will occlude. The archforms for the maxillary tooth placement are illustrated in **Fig. 4B**.

[0079] The vertical positioning of the remaining teeth takes into account the occlusion and other prescription information input in step (200). The remaining calculations are at forth in detail below.

*(96) <u>Appliance Design Procedure</u>:*

[0080] The appliance design procedure (96), as illustrated in the flowchart of **Fig. 2C**, calculates the dimensions of the appliance components in a form capable of being translated into NC codes for operating NC machinery for production of the appliance components, such as the brackets and archwires and also placement jigs for installing the brackets in the proper positions on the teeth of the patient. In the appliance design procedure (96) includes the following steps (1200) through (1800). These include :

(1200) The mandibular archwire plane step in which the plane of the archwire for the mandibular teeth is defined in relation to the teeth of the mandible.

The archwire should preferably lie in a literally flat plane and be symmetrical about the midline of the arch. As such, the archwire will be properly shaped for installation with either side facing upward. (1300) The mandibular slot inclination step in which the angles of the slots of the mandibular tooth brackets of the appliance are calculated.

(1400) The maxillary archwire plane step in which the plane of the archwire for the maxillary teeth is defined in relation to the teeth of the maxilla.

(1500) The maxillary slot inclination step in which the angles of the slots of the maxillary tooth brackets of the appliance are calculated.

(1600) The mandibular archwire and bracket in-out dimension calculation step in which the slot depth and bracket geometry is calculated for the mandibular tooth brackets.

(1700) The maxillary archwire and bracket in-out dimension calculation step in which the slot depth and bracket geometry is calculated for the maxillary tooth brackets. In determining the in-out dimensions, the deepest and shallowest slot depths are determined, and the smoothest archwire curve, namely that with least variation in radius change along the curve, and preferably with no inflection points, which passes between the depth limits is determined.

(1800) The bracket placement jig designing step in which placement jigs are designed for use in property positioning the custom designed brackets on the patient's teeth.

[0081] In **Fig. 8D**. a plastic jig 82 is shown which engages the walls and bottom of the bracket slot fully. Additionally, the portion of the jig 82 contacting the tooth designed to be formed to precisely fit the known contour of the tooth, as determined by the profiles input in step (500). This assures that the bracket slot and hence the bracket is placed at precisely the correct height when bonded to the tooth.

*(97) <u>Appliance Manufacturing Procedure</u>:*

[0082] The appliance manufacturing procedure (97), as illustrated in the flowchart of **Fig. 2D**, entails the generation of controller codes for NC machinery to produce the brackets, archwires and bracket placement jigs designed in the appliance design procedure (96), and the manufacture of the appliance components with the use of the machinery controlled by the codes. The procedure (97) includes the steps of:

(3000) Controlling and operating the bracket forming machinery 39 to produce the custom brackets.

(3200) Controlling and operating the Wire-bending machinery 40 to produce the custom archwires:

(3500) Controlling and operating the jig forming machinery 41 to make custom placement jigs for the location of the brackets on the patient's teeth:

*(98) <u>Appliance Transmission Procedure</u>:*

**[0083]** One of the ultimate objectives is to place the custom orthodontic appliance 25 into the hands of the orthodontist 14, along with the tools and information necessary for the proper installation of the appliance 25 in the mouth of the patient 12 to treat the patient by moving the patient's teeth to the calculated finish positions. This is best understood by reference to **Fig. 1**.

**[0084]** Referring to **Fig. 1**, as set forth above, the configuration of the preferred system 10 will vary depending on the nature and scale of the orthodontist's practice. Preferably, all or much of the appliance design portion of the procedure (87) takes place at an appliance design facility 13, although in a large scale orthodontic clinic, the entire process could be carried out at the patient treatment location. Usually, however, the functions performed in the design computer 30b, or design portion of the computer 30, are carried out at the appliance facility 13, together with some of the manufacturing functions performed by manufacturing control computer 30c and the appliance manufacturing equipment 38.

**[0085]** In the configuration where, as illustrated, some or all of the appliance 25 is made at the appliance facility 13, the custom appliance 25 is transmitted to the orthodontist 14. Along with the appliance 25 is communicated documentation in the form of a hard copy printout of information 37 generated by the design computer 30b, which could also include documentation of the input data that made up the data 26 and the prescription information 27, and a printout of parameters recorded by the manufacturing computer 30c.

**[0086]** The transmitted appliance 25 includes a set of archwires 64, as illustrated in **Figs. 8E** and **8F**, a complete set of custom brackets 80, as illustrated in **Figs. 8D** and **8F**, and the placement jigs as illustrated in **Figs. 8D** and **9T** through **9W**. Along with the jigs 82 are included a set of adapters 84 that are used to align the slots 80b of the brackets 80 with coplaner slots 84a of the jigs 82. The appliance and the bracket placement jigs therefor are similar in the case of lingual appliances, a bracket for which is illustrated on a tooth in **Fig. 8G** while the lingual appliance is shown positioned on the mandibular teeth in **Fig. 8H**.

**[0087]** In addition, custom archwires 64 are transmitted so the orthodontist 14. These archwires include archwires in the exact form, as illustrated in **Fig. 8E**, to move the teeth to their finish calculated positions, as illustrated, for example for the lower teeth, in **Fig. 4D**. In **Fig. 4D**, the archwire 64 is shown in the unstressed state (or having nominal residual stress sometimes motivating some orthodontists to prescribe overcorrection) that it will attain when the appliance 25 has moved the patient's teeth to the calculated finish positions. This is the same shape as the archwire of **Fig. 8E** shipped to the orthodontist 14. This finish arch wire will be of a material and stiffness determined to be appropriate for the final positioning of the teeth. Depending on the severity of the initial malpositioning of the patients teeth, however, less stiff archwires, or temporary archwires may be desired for beginning the orthodontic treatment. Thus, additional archwires 64 of various properties but in the shape shown in **Fig. 8E** will be provided to the orthodontist 14. In addition or in the alternative to the provision of these additional archwires, an actual size drawing or template having thereon the shape shown in **Fig. 8E** will be provide to the orthodontist 14 to enable him so form archwires for preliminary treatment and rough positioning.

**[0088]** In alternative configurations, information may be sent from the design computer 30b in machine readable form, for example by diskette 34 or modem, to a manufacturing computer 30c to which is attached one or more of the appliance component manufacturing machines 38.

*(89) <u>Patent Treatment Operation</u>*

**[0089]** The patient treatment involves, first, the assembly of the respective bracket 80, jig 82 and adapter 84 combinations, as illustrated in **Fig. 8D**, and the application of the brackets 80 thereby to the patient's teeth. This involves the application of adhesive to the area generally in the enter of the face of the tooth, either labial or lingual, to which the brackets 80 are to be applied. This illustrated in **Fig. 8D**, for example, with the application of a bracket 80 to the labial face of a maxillary incisor $T_{U,1}$. The assembly is positioned on the tooth with the blade of the jig 82 positioned on a generally vertical labial lingual cross section through the approximate center of the tooth, in the plane that may be said to contain the crown long axis *CLA* of the tooth.

**[0090]** When the bracket adhesive has set, the bracket placement jig 82 is removed by first sliding out adapter 84 mesiodistally and then sliding the jig 82 off of the incisal edge of the tooth, leaving the bracket in the calculated position.

**[0091]** Then, with the brackets 80 set on the teeth the archwire 64 is installed. Often, the first archwire installed will be one of lower stiffness than the final archwire. In the example of **Fig. 8F**, the mandibular teeth in their initial position as illustrated in **Figs. 4** and **4A** are shown. The brackets 80 are positioned on the teeth in the exact same positions as

shown in the calculated finish position diagram of **Fig. 4D**. Because the teeth are not yet in this ideal finish position, the archwire 64, when inserted into the archwire slots and tied to the brackets 80, will be stressed into the elastically deformed condition shown in **Fig. 8F**. This stressed condition of the archwire 64 operates, without the need of the orthodontist to artfully bend the wire, to apply the forces to the teeth to urge them toward the ideal positions of **Fig. 4D**. This force will continue to be applied until the teeth have moved to the finish positions. In some prescribed forms of treatment the, wire and brackets are designed to move the teeth to a slightly overcorrected position to allow for a relaxation movement of the teeth when the appliance 25 is removed.

<u>DETAILS OF STEPS OF APPLIANCE ANALYSIS, TOOTH POSITION CALCULATION, AND APPLIANCE DESIGN AND MANUFACTURING OPERATION (87)</u>

**[0092]** The analysis, design and manufacturing operation (87), as stated above, includes the (94) input, (95) analysis, (96) design, (97) manufacturing, and (98) transmission procedures of a computerized custom designed appliance manufacturing operation.

*<u>Digitized Input Procedure</u> (94)*

**[0093]** The input of digitized information includes the (100) input of patient and doctor identifying information, (200) the input of patient background information, (300) the input of digitized information of the horizontal dimensions of the mandibular teeth and the mandibular bone, (400) the input of horizontal dimensions of the maxillary teeth, and (500) the input of vertical labial-lingual profile information of each of the individual teeth.

*(100) <u>Identification Information Input Step</u>:*

**[0094]** The input of the doctor-patient identification information 17 includes the substeps, performed by an operator 28 in response to prompts for text input at a terminal of the computer 30, of doctor's name, doctor's identification number, and patient's name. Then, the computer 30 (120) assigns a patient identification number. With this information, (125) a patient-specific floppy disk or diskette 34 is automatically formatted.

*(200) <u>Patient Background Input Step</u>:*

**[0095]** Entry of patient background information 19, and the prescribed treatment information 27 from the doctor involves entering, from the background information 19, the patient's age sex and race and selecting from multiple choice prompts, such as

Whether treatment is to include an extraction, and if so, which teeth,
Whether the occlusion type is a group function or a cuspid rise, and if a cuspid rise, whether averages or individual head film is to be used,
Whether to preserve lower intercuspid distance or allow expansion, and if expansion is to be allowed, how much expansion,
Whether or not the occlusion is mutilated,
Whether a Steiner compromise is to be allowed,
Whether a Roth or Ricketts inset is to be used on upper laterals, and if so which,
Whether a Roth or Andrews upper lateral overbite is indicated, and if so, which,
the preferred slot size,
Whether the case is to be treated with labial or lingual appliances,
Whether the case is to be diagnosed using symmetry or not, or
How inter-incisal angle is to be determined, using the Andrews Norms, the Parallel Upper Central to Facial Axis Norm, or Ricketts Norm.

*(300) <u>Mandible Digitized Video Input Step</u>:*

**[0096]** The (300) inputing of video or other graphics top view image of the patient's lower jaw, including the teeth, is illustrated in Fig. 3, and includes the digitizing and processing of the data of the widths of the mandibular teeth and size and shape of the mandibular bone or bone of the lower jaw 22 of the patient 12 from the horizontal plan view of the lower jaw as in **Fig. 4**.

**[0097]** The roots of the lower teeth of the patient are contained within the mandibular trough *MT*, which is defined as the space between boundaries $B_L$ and $B_B$ of **Fig. 4**. The outer, or buccal, and inner, or lingual, boundaries $B_B$ and $B_L$,

respectively, are preferably digitized by interactive selection by the operator 28 from an image 48 of the cortical bone of the mandible 22 on the screen 35. Furthermore, the mandibular teeth must lie in the arch in contact with one another. They each occupy a portion of the arch equal to the distances between their mesial and distal contact points with the adjacent teeth.

[0098] A grid *G* is overlaid to define *X,Y* coordinates with a *Y* axis on a midline *ML* of the lower jaw 22 and an *X* axis perpendicular to the *Y* axis through a selected intersection point or origin *0,0*, preferably set at the mesial contact points of the lower central incisors.

[0099] The operator sequentially selects each point, first for the individual tooth contact points, then the jaw bone boundaries. From the *X,Y* coordinates of $M_{X,Y}$, $M_X$ and $M_Y$. and of $D_{X,Y}$, $D_X$ and $D_Y$, the mesio-distal width $MDW_I$ of each tooth *I*, on each side of the mandible 22, is calculated using Pythagorean theorem:

$$MDW = \sqrt{(M_X + D_X)^2 + (M_Y + D_Y)^2}$$

where:

$M_X$ is mandibular *X* coordinate;
$M_Y$ is mandibular *Y* coordinate;
$D_X$ is distal *X* coordinate; and
$D_Y$ is distal *Y* coordinate.

[0100] The total length is *MAL*

[0101] From the selected intersections of the lines of the grid *G* with the mandible boundaries $B_B$ and $B_L$, cartesian coordinates $La_{X,Y}$ and $Li_{X,Y}$ labial and lingual limits, respectively, of cortical bone on both sides of mandibular jaw are generated, and midpoint coordinates $MP_{XY}$ are calculated as are the bone width distances between each of the respective labio-lingual pair *DLL*, as follows:

$$MP_X = La_X + \frac{Li_X - La_X}{2}\ ;\ MP_Y = La_Y + \frac{Li_Y - La_Y}{2}$$

$$DLL = \sqrt{(La_X + Li_X)^2 + (La_Y + Li_Y)^2}$$

[0102] The sum of the individual mandibular tooth widths *MDW* equals the total dental length or mandibular arch length *MAL* contained in the mandibular trough equation *MTE* that will be constructed through the points $MP_{X,Y}$. *MAL* is referred to as the arch perimeter.

[0103] At this stage, the midpoints are typically averaged right to left to eliminate any asymmetry that may be present due to alight measurement errors unless the patient has been diagnosed to be of any asymmetrical anatomy.

[0104] The midline *ML* shown in **Fig. 4** is the axis of such symmetry corrections. These corrections for each point $MP_{X,Y}$ are calculated as follows:

$$S_X = MP_X + \frac{PR_X - PL_X}{2}\ ;\ S_Y = MP_Y + \frac{PR_Y - PL_Y}{2}$$

where:

$S_{X,Y}$ is the symmetricalized point $MP_{X,Y}$;
$PR_{X,Y}$ is a point $MP_{X,Y}$ on the right side and
$PL_{X,Y}$ is the corresponding point on left side of the trough

[0105] With the completion of this symmetricali-zation process, a mathematical equation *MTE*, which describes the size and shape of the mandibular trough is derived by fitting a curve to the points $MP_{X,Y}$. Preferably, this curve is derived by fitting a series of cubic equations, such as a cubic spline equation, to pass smoothly through the points, for example, through the averaged midpoints $S_{X,Y}$.

[0106] The cubic equations are then preferably converted in form to a series of segments of tangent circle equations with slopes equal to the slopes of the cubic splice at the midpoints, and equal to the slopes of the adjacent circle seg-

ments at the segment end points, or their points of intersection, along the curve. To fit a cubic equation with quadratics, two circles *CS* and *CL* are used to describe each segment of the *MTE* between midpoints, as illustrated in **Fig. 5**. This allows a smooth curve consisting of tangential circles to represent the mandibular trough.

**[0107]** The spline-to-circle conversion routine is described in further detail under routine (2100) below.

**[0108]** Cartesian coordinates are input for right and left mandibular cuspid cusp tips *CR* and *CL*, respectively, as illustrated in **Fig. 4**. A distance *DCT* between the cusp tips *CR* and *CL* of the two mandibular cuspids is then calculated:

$$DCT = \sqrt{(CR_X + CL_X)^2 + (CR_Y + CL_Y)^2}$$

**[0109]** This information is used to calculate if and how much the mandibular intercuspid distance is to be altered, and to evaluate whether the calculated final position is acceptable. Similarly, cartesian coordinates or right and left mesiobuccal cusp tips, *MR* and *ML*, respectively, of mandibular first molars are calculated, and the distance between these points *DMT* is calculated:

$$DMT = \sqrt{MR_X + ML_X)^2 + (MR_Y + ML_Y)^2}$$

**[0110]** This information is used to determine if and how much the mandibular intermolar distance is to be altered.

*(400) <u>Maxilla Digitized Video Input Step</u>:*

**[0111]** As with the mandibular jaw information described in connection with **Fig. 4**, a computer image is made in the same manner from the upper modal 23 of the maxillary jaw 24 from the image 48a illustrated in **Fig. 4A**.

**[0112]** Coordinates $R_{x,y}$, $L_{x,y}$ of the central fossae of right and left maxillary first molars are input. Then, the distance between central fossae *DCF* is calculated as follows:

$$DCF = \sqrt{(R_X + L_X)^2 + (R_Y + L_Y)^2}$$

**[0113]** This information is recalculated after the tooth finish positions are calculated to coincide with the *DMT* spacing of the mandibular first molars, and compared with this initial measurement as an indicator of whether the intermolar width will be changed by treatment and the amount of such change, if any.

*(500) <u>Digitized Probe Tooth Profile Input Step</u>:*

**[0114]** In this step, selected profiles of each of the teeth are generated from either the model 20, or from a digitized three dimensional representation of the patient's teeth or the model 20 as illustrated in **Figs. 3A** and **3B**. In the illustrated embodiment, the use of the probe assembly 57 of **Fig. 1C** is used in this step.

**[0115]** The selection of the profile plane is illustrated in **Fig. 6** where a first profile $PF_A$ through the center of the tooth is shown as missing the buccal cusp tip which is the maximum crown highpoint of the tooth. Profile $PF_B$ is then selected to include the buccal cusp, and the ridge of the profile is found to generally align with the low point of $PF_A$. Alternatively, the profile may be non-planar to pick the important features of both planes. As such, the profile produced will be comparable to a projection onto a plane of the relevant tooth extremities.

**[0116]** The resulting profiles $PF_i$ are illustrated in **Fig. 3C**.

*(95) <u>Analysis and Finish Tooth Position Calculation Procedure</u>*

**[0117]** The calculation of the finish positions of the teeth, as illustrated in the flowchart of **Fig. 2B**, includes (600) determining the relative positions of geometric landmarks on the surfaces of the teeth and establishing the axis inclinations of the teeth, (700) calculating cuspid rise, (800) initially positioning the mandibular teeth vertically and in relation to the mandibular trough, (900) calculating a best fit cusp tip equation for the mandibular teeth, (1000) calculating the finish positions of the mandibular teeth on the best fit equation, and (1100) calculating the finish positions of the maxillary teeth on three arches related to the best fit equation.

*(600) <u>Tooth Landmark Identification Analysis Step</u>:*

**[0118]** The input data 26 is analyzed to develop or derive further parameters for calculating the final positions of the

teeth and for (96) the design of the appliance 25. In the tooth positioning analysis (95), as illustrated in the flowchart of **Fig. 2B**, (600) a tooth profile analysis is made in which, for example, certain anatomical landmarks are chosen, depending on the tooth to be analyzed.

**[0119]** In the tooth profile analysis step, individual images 63 of the profile curves $PF_i$ of each tooth (**Fig. 3C**) are recalled separately to the screen of the computer 30b for selection of the landmarks. Using the displayed images 63 of the profile curves $PF_i$, specific landmark points are chosen, first on the mandibular molars and bicuspids. The selected points are digitized as illustrated in **Fig. 6**. The selected points are:

Point $P_1$: The Lingual (tongue side) gum/tooth intersection.
Point $P_2$: The prominence of the lingual cusp.
Point $P_3$: The prominence of the buccal (cheek side) cusp.
Point $P_4$: The buccal gum/tooth intersection.

**[0120]** From these landmarks, (615) the crown long axis *CLA* of each molar and bicuspid profiled is determined. The determination is made by constructing a first line $L_1$ between points $P_2$ and $P_3$ and a second line $L_2$ between points $P_1$ and $P_4$. The crown long axis *CLA* of a tooth is the line between the midpoints of $L_1$ and $L_2$.
**[0121]** A point $P_{2\text{-}3x,y}$ equidistant between points $P_2$ and $P_3$ along line $L_1$ is then calculated, and a point equidistant between points $P_1$ and $P_4$ along line $L_2$ is also calculated and defined as the Gingival Center Point *GCP*.
**[0122]** The line defining the crown long axis *CLA* is constructed using the following equation: where:

$X_{2\text{-}3}$, $Y_{2\text{-}3}$ = $X$ and $Y$ coordinates of the center point $P_{2\text{-}3}$.

$$\frac{Y - Y_{2\text{-}3}}{X - X_{2\text{-}3}} = \frac{Y_{GCP} - Y_{2\text{-}3}}{X_{GCP} - X_{2\text{-}3}}$$

$X_{GCP}$ $Y_{GCP}$ = $X$ and $Y$ coordinates of gingival center point $GCP_{X,Y}$.

**[0123]** For molars and bicuspids, point $P_3$, the buccal cusp tip, is defined as the Incisal Center Point *ICP*.
**[0124]** Similarly, the anatomical landmarks and crown long axis *CLA* for the mandibular cuspids, laterals and central teeth are determined, as illustrated in **Fig. 6B**. The point $P_1$ through $P_4$, as labeled in **Fig. 6B**, are selected as follows:

Point $P_1$: The lingual gum/tooth intersection.
Point $P_2$: The lingual aspect of the incisal edge.
Point $P_3$: The buccal aspect of the incisal edge.
Point $P_4$: The facial gum/tooth intersection.

**[0125]** As with the bicuspids and molars, lines $L_1$ and $L_2$ are constructed. The landmarks in the cases of the teeth as illustrated in **Fig. 6B**, are chosen because they are relatively tolerant to operator error in selection. This can be seen by the set of broken lines that are possible alternatives to $L_2$ in **Fig. 6B**. From these landmarks the crown long axis *CLA* is determined as defined above, by connection of the midpoints of $L_1$ and $L_2$.
**[0126]** For maxillary dentition for each upper molar and bicuspid, antomical landmarks are identified and chosen as illustrated in **Fig. 6C**, which requires the selection of a fifth point. $P_5$, the mesial marginal ridge of the tooth at central groove.
**[0127]** Next, as further illustrated in **Fig. 6D**, seed values for setting the crown long axis inclinations *LAI* of the teeth. Initially, such seed values may be derived from analyses that identified the facial axis plane *FAP* through the facial axis point *FA* of the tooth (the midpoints of the height of the clinical crowns along the facial axes of the clinical crowns).
**[0128]** The computer images as summarized in **Fig. 3C** for each tooth are then rotated so that the *CLA* is oriented at the desired angle *LAI*, the long axis inclination angle, to the mandibular trough plane *MT*. This computes the final inclinations of the teeth that will be preserved in the calculations below. This produces the oriented profiles *PF* summarized in **Fig. 6E**.
**[0129]** Once the tooth profiles have been rotated to the inclination angles *LAI*, certain precise vertical dimensions and extremities can be determined. From the digitized profile curves, which are stored in memory in the form of a series of closely spaced points, the precise incisal tip *IC*, as illustrated in **Figs. 6F, 6H** and **6I**, are identified on the cuspids, laterals and centrals.
**[0130]** Additionally the elevation of the marginal ridge $P_5$ is identified. The marginal ridge elevation *MRE*, which is the vertical distance from $P_3$ to $P_5$, is identified on the maxillary posterior teeth because they are the centric stops for the buccal cusps of the mandibular molars and bicuspids. as illustrated in phantom line $PH_1$, in **Fig. 6C**. The *MRE* is used

as the buccal cusp height *BCH* in the calculation of cuspid rise and archwire plane placement as described below in the discussion of **Figs. 7A** and **8**, respectively.

*(700) <u>Cuspid Rise Determination Step</u>:*

**[0131]** The cuspids ($I$=3) are close to the front of the mouth and are therefore further from the condyle or pivot point PP of the jaw than are the posterior teeth ($I$>3), as illustrated by distances $DJ_I$ in **Fig. 7**. This results in the teeth closer to the back of the mouth moving less than the cuspids on opening. This differential rate of movement must be included in the calculation of cuspid rise or the back teeth will remain in contact after the cuspids have cleared each other. Also, the distance *DPP* from the occlusal plane to the pivot point *PP* of the condyle of the jaws must be considered, as illustrated in **Fig. 7**.

**[0132]** Preferably, where cuspid rise is prescribed to control occlusion, the contribution of cuspid rise is distributed between the maxillary and mandibular cuspids, with two parts of the cuspid rise provided by the maxillary cuspids and one part by the mandibular cuspids.

**[0133]** The initial vertical distance or buccal cusp height *BCH* from $P_3$ to the marginal ridge for each of the right and left maxillary first bicuspids *T(U,4)*, second bicuspids *T(U,5)*, first molars *T(U,6)*, and second molars *T(U,7)*, as illustrated in **Fig. 6C**. Then, from anatomical study, the cuspid rise vertical height *CR* required to clear each respective pair of teeth is determined by first computing the values in Table 1, which are derived from the jaw dimensions *DPP* and $DJ_I$ in **Fig. 7**. required to clear each respective pair of teeth is determined by first computing the values in Table 1.

TABLE 1

*1.67 x BCH of T(U,7)*

*1.50 x BCH of T(U,6)*

*1.36 x BCH of T(U,5) and*

*1.20 x BCH of T(U,4).*

**[0134]** Then, from the products of the buccal cusp height *BCH* for each such tooth multiplied by the rise factor listed above, the largest value is selected. This selected product is the cuspid rise required to clear the most prominent cusp and provide group function occlusion. This is illustrated as $BCH_4$ in **Fig. 7A** for the case where the first molars are the last to clear.

*(800) <u>Mandibular Tooth Placement Step</u>:*

**[0135]** The first calculation places the tips of the mandibular teeth on an occlusal plane pending final refinement of the placement, as diagrammatically illustrated in **Fig. 6E**. In this step, the pending final refinement of the placement, as diagrammatically illustrated in **Fig. 6E**. In this step, the inclinations of the mandibular tooth crown long axes *CLA* are preserved, and the teeth are moved upward along their *CLA's* until their tips are in alignment with the plane of the top of the tallest tooth. The *CLA's* are placed to intersect the *MTE* below the tooth *GCP*. Because the teeth are inclined at different *LAIs*, or long axis inclination angles, the tooth tips will each be differently offset from the *MTE*, and thus not in smooth arch.

**[0136]** The tallest mandibular tooth, with the exception of the cuspids, is identified. In **Fig. 6F** this is illustrated as the left mandibular central. The tallest tooth is the tooth with the greatest crown height *CH*. The crown height *CH* is the distance, in the *Y* direction (with the teeth profiles oriented a described in step (600), from the a *GCP*, the point of intersection of line $L_2$ and crown long axis *CLA*, to highest point on buccal cusp, e.g. $P_5$ (for posterior teeth) as illustrated in **Fig. 6F** and (for the anterior teeth) to either the incisal center point *ICP* or, preferably to the incisal tip *IC*, as illustrated in **Fig. 6G**. The crown height *CH* of the tallest tooth, shown as the left mandibular central incisor in **Fig. 6F**, is the maximum crown height *MCH* of the mandibular teeth.

**[0137]** Three parallel planes are established:

an *MCH* reference plane *MCHP* parallel to the X-axis, and passing through an origin *0,0*, set at the *GCP* of the tallest tooth (**Figs. 6F** and **6I**);

a Buccal Cusp Plane *BCP* parallel to X-axis and passing through coordinates *0, MCH* on the tallest tooth (**Figs. 6F** and **6I**); and

a Cuspid Rise Plane *CRP* parallel to *X*-axis and passing through coordinates *0, CR* where *CR* is the cuspid rise calculated in step (700), where the cuspid rise option has been selected.

[0138] With the planes defined, the oriented mandibular teach are placed such that the highest point on buccal cusp tip $P_3$ or incisal tip *IC* of each contacts the buccal cusp plane *BCP*, for all teach except the cuspids, as illustrated further in **Fig. 6F**. The *BCP* thereby is established as the occlusal plane *MOC*. The reference plane *MCHP* is set equal to the plane of the mandibular trough *MT*. This sets the *GCP* of the tallest tooth on the *MT*, with the *GCP's* of the remaining mandibular teeth above it. It also sets the occlusal plane *MOC* a distance *MCH* from the mandibular trough *MT*. The absolute highest point on a tooth crown is preferably used to align the teeth with the *BCP*. Such a point can be determined by additional point selection in step (500), such as by the direct selecting of the point *IC* for the precise incisal tip, or preferably by calculating the highest point directly from the profiles of Fig. 3C or from three dimensional images as in Figs. 3A, 3B after rotation of the teeth to their final inclination angles *LAI*, at the end of step (600).

[0139] At this stage, the vertical positions of the mandibular teeth relative to each other as illustrated in **Figs 6F** and **7C** are calculated.

[0140] The teeth are then horizontally set at temporary positions with respect to the *MTE*, which lies in the plane of the mandibular trough *MT* (*MHCP*).

[0141] The preferred goal, is to position the tips of the teeth in the smoothest arch in an occlusal plane *MOC* rather than their gingival aspects in a smooth arch at the mandibular trough *MT* so a horizontal distance *OFFSET* for each tooth is calculated, based on the tooth and the crown long axis inclination *LAI* determined in step (600). This offset is the horizontal distance from the *MTE* to the tooth tips when their *GCP's* are placed on the *MTE*.

[0142] For mandibular centrals and laterals and cuspids, the *OFFSET* is calculated by dividing, by the tangent of *LAI*, the vertical distance from (1) the intersection of crown long axis *CLA* and the incisal tip *IC* to (2) the intersection of *CLA* and maximum cusp height reference plane *MCHP*. The vertical distance may be calculated from the *IC* to the *MCHP* (equal to the *Y* coordinate of point *IC*, producing the incisal center vertical distance *ICD*.) For mandibular laterals and centrals, *ICD* equals *MCH*. For mandibular cuspids, *ICD* equals the mandibular cuspid rise component, which is *MCH* + *(Total CR)/3* when cuspid rise function occlusion has been selected. The calculation of the *OFFSET* for centrals, laterals and cuspids would thus be as follows for the incisors and laterals:

$$OFFSET = ICD/tan(LAI).$$

[0143] For mandibular bicuspids and molars, referring to **Fig. 6F**, the *OFFSET* is calculated as the horizontal distance from point $P_3$ to the intersection of the *CLA* and the *MCHP* as follows:

$$OFFSET = [MCH/tan\ (LAI)] + HD,$$

where *HD* equals the horizontal distance from point $P_3$ to incisal center point *ICP*.

[0144] Then, the mandibular trough placement point *MTPP* is defined as the intersection of *MCHP* and *CLA*, as illustrated in **Figs. 6G** and **6H**. For the tallest tooth, *MTPP* is its *GCP*, as illustrated in **Fig. 6I**. The *MCHP* is at the level of the mandibular trough and contains the *MTE*. The *MTPP* is the point on the tooth that is initially placed on the *MTE*.

[0145] Next, referring to **Fig. 7B** and **7C**, the teeth are placed with their *MTPP's* on the mandibular trough, one side at a time. To achieve this, a tooth placement routine is called, in which the mandibular trough equation *MTE* is first adjusted for the mandibular entrain to increase the radii by the amount of the central *OFFSET* for that particular tooth, as defined above, to form a mandibular trough offset curve *MO(1)* of **Fig. 4B**. The radii of the *MTE* referred to are those of the *MTE* defined in the circle segment form of the equation generated in step (300) with the spline to circle conversion routine

[0146] Since the *OFFSETs* of the teeth differ, the *MO* may be viewed as a discontinuous equation when constructed in this manner, made up of segments, each containing the tip of one tooth and spaced labial-lingually from the *MTE* by the amount of the individual tooth's *OFFSET*.

[0147] Beginning with the left side, the central is placed, as illustrated in **Fig. 7B**, by placing its mesial contact point *MCP* at the intersection of the midline *ML* with the offset curve *MO* for the tooth. This has the effect of the placing *MTPP* of the tooth, which is the intersection of the *CLA* with the *MCHP* or *MT*, on the *MTE* and the incisal tip *IC* of the tooth on $MO_1$ The tooth placement on the circle segment form of an equation is explained in detail in the description of the tooth placement routine. In the placement of the central, a circle $C_1$ is constructed with a radius equal to the mesiodistal width $MDW_1$ of the central tooth and with the center of the circle $C_1$ at the mesial contact point *MCP* of the tooth at intersection of the midline *ML* with the offset curve $MO_1$. Then, circle $C_2$ is constructed with a radius equal to *MDW/2* and with its center coincident with the center of circle $C_1$. Then, the intersections of trough offset curve *MO* with the circles $C_1$ and $C_2$ are found, its intersection with the circle $C_1$ being the distal contact point *DCP* of the tooth and its intersection with the circle $C_2$ being the tooth midpoint *TMP* of the central tooth. The tooth midpoint *TMP* is here defined as the midpoint of the mesiodistal width of the tooth placed on an archform, which is the intersection of the archform with a vertical labial-lingual plane that contains the *CLA*. This mid-point *TMP* of the central tooth on the *MO* is the approximate position of the incisal tip *IC*.

[0148] Determining the intersections of the circles with the offset trough *MO*, or expanded mandibular trough, requires identification of which circle sector lines (**Fig, 5-5P**) the circles $C_1$ and $C_2$ intersect. These are identified by comparison of the *X* coordinates of the intersections with the *X* coordinates of the distal contact points *DCP* of each of the central teeth to determine which segments of the trough equation will be used, as explained more fully in the description of the tooth placement routine.

[0149] Finally, a distal contact point line *DCPL* is constructed for the central tooth through the *DCP*, at the intersection of circle $C_1$ with the *MO*, and through the center of the identified circle segment of the *MO*, the expanded *MTE*, on which the *DCP* of the tooth lies. This line lies along a radius of the circle segment of the *MO* curve through the distal contact point of the central tooth. Similar lines *DTMP* are constructed for the center of the tooth *TMP*.

[0150] For each of the remaining mandibular teeth on the same side of the arch, in distal sequence, a new mandibular trough offset $MO_i$ is calculated, by expanding the *MTE* with radii of curvature increased by the amount of the next tooth's *OFFSET* and with center of the circles $C_1$ and $C_2$ moved labially or outwardly from the *MTE* along the prior tooth's distal contact point line *DCPL* by the amount of the current tooth's *OFFSET*. This is the *MCP* for the next tooth. Circle $C_1$ for the tooth is constructed with a radius equal to the mesiodistal width of the tooth and with its center at their center point *MCP*. Circle $C_2$ is constructed with a radius equal to *MDW/2* and with centers coincident with circle. *C1*.

[0151] For bicuspids and molars, the tooth midpoints *TMP* can be considered a their points $P_3$. Then, as with the central, the intersections of *MO* and circle. $C_1$ and $C_2$ are calculated for these teeth. The dial contact points *DCT* of these teeth are at the intersections of *MO* for the tooth and the respective $C_1$s. The centers of the teeth *TMP* are at the intersections of *MO* for the tooth and the respective circles $C_2$. The *MO* sector segments which the circles intersect are identified. Selection of the segments is made by comparing the *X* and *Y* coordinates of intersections to *X* and *Y* coordinates of distal contact points *DCPs*. Finally, a distal contact point line *DCPL* is constructed from selected segment center to the plane *DCP*. The same is done for the centers of the teeth *TMP*. When tooth placement is referred to below, this is the sequence that is preferably followed.

*(900) Best Fit Mandibular Arch Equation Step:*

[0152] The discontinuous offset equation *MO* contains the approximate tips of the teeth in the occlusal plane *MOC*, with the teeth irregularly offset as represented by the discontinuous *MO* lines in **Fig. 4B**. To place the tips of the teeth into an ideal arch, (900) a final equation for better placement of the buccal cusp tips and incisal edge of the mandibular teeth in continuous arch is developed.

[0153] The equation is statistically developed that best fits the cusp tips and incisal edges of the individual teeth; a Best Fit Buccal Cusp Equation *BFBCE*. In the formulation of the equation, the coordinates of the right and left tooth midpoints *TMP*, the *ICPs* or *ICs* in **Fig. 7B**, are preferably averaged. The equation *BFBCE* may be obtained by use of polynomial or other bezier or least square statistical techniques to arrive at a best fit equation. These are available in any of a number of off-the-shelf software packages.

[0154] Such a *BFBCE* equation is plotted in **Fig. 4B**. Once the *BFBCE* is determined, it my be converted to a circle segment equation in a manner such as with the spline to circle conversion routine above.

*(1000) Mandibular Best Arch Placement Step:*

[0155] After statistically deriving a best fit equation *BFBCE*, (1000) positions of the individual mandibular teeth are calculated to translate them facially, either labially or lingually, so that their tips fall on the best fit curve.

[0156] To achieve this, the mesiodistal contact point of the mandibular central, the point *MCP*, as in **Fig. 7B**, is first placed on the intersection of the midline *ML* with the BFBCE in the same manner as it was placed on the *MO* in step (800). Then circles *C1* and *C2*, as defined above, for the tooth are constructed and their intersections with the *BFBCE* curve are found. As with the placement in step (800) above, the intersection of $C_1$ with *BFBCE* is the distal contact point *DCP* of the tooth, and the intersection of $C_2$ with the *BFBCE* curve, is the center point *TMP* (which aligns with *IC*) of the tooth. This, in effect, moves the tooth normal to the circle segment of the *BFBCE* associated with the *TMP*. Then, new circles $C_1$ and $C_2$ are constructed with centers at the distal center points *DCP* and substeps are repeated for all teeth on the same side and then the opposite side of the mandibular arch.

[0157] The finish positions of the mandibular teeth are illustrated in **Fig. 7C** in which the *X-Y* coordinates are those of the horizontal arch planes. A vertical *Z* coordinate, perpendicular to the horizontal X-Y plane, is aligned with the *Y* axes of the individual tooth profile planes. The *X* coordinates of the profile planes are aligned with the labial-lingual directions *La-Li* in **Fig. 7B**.

*(1100) Maxillary Tooth Placement Step:*

[0158] The construction of occlusion requires the fitting of the maxillary teeth to the already positioned mandibular

teeth. This is accomplished by deriving a modified best fit buccal cusp equation *BFBCE* for the maxillary teeth. With the maxillary teeth, the cusp tips of the posterior teeth and incisal edges of the anterior teeth are not set in a single arch, but rather place (1) the central groove-marginal ridge points of the maxillary bicuspids and molars on the *BFBCE*, (2) the maxillary anteriors spaced labially off the *BFBCE* to allow for incisal overlap and a clearance between the lingual surfaces thereof and the labial surfaces of the mandibular teeth, and (3) the cuspid tips in the arch generally between the first maxillary bicuspid and the lateral incisor. The arches on which the maxillary teeth are placed as illustrated in **Fig. 4C**, as explained above.

**[0159]** For the maxillary incisors, the modification of the *BFBCE* first involves an averaging the distances from point $P_2$ to point $P_3$ on the mandibular incisor incisal edge, and dividing by two, to locate the arch that will contain the labial surface of the tooth adjacent the incisal center point *ICP* of the tooth, which is generally the point $P_3$. This produces a uniform distance from the best fit equation to the contact point of the facial surface on the labial side of the mandibular anterior teeth with the facial point on the lingual side of the maxillary anterior teeth. An additional distance, of typically one-quarter millimeter, is added to the averaged distance to provide a slight *Clearance* between the upper and lower anterior teeth. This is illustrated in **Fig. 7D**.

**[0160]** The maxillary anterior denitition is set for vertical position relative to the occlusal plane *MOC* according to occlusion criteria selected to provide a predetermined overlap. From the cuspid rise calculation of step (700), the vertical positions of the maxillary cuspids are known relative to the mandibular occlusal plane *MOC*. For maxillary laterals and centrals, the vertical positions provide the overlaps according to the prescribed criteria, putting their lingual facial contact points with their mandibular counterparts on the *MOC* plane. All teeth are inclined at the prescribed crown long axis *CLA* inclination values *LAI* from step (600).

**[0161]** In the (1100) placement of the teeth of the maxilla, or upper jaw 24, with respect to those of the mandibular, or lower jaw 22, the maxillary anterior arch form *MAAF*, the central groove marginal ridge arch form *CGMRAF*, and the maxillary cuspid arch form *MCAF*, are defined as illustrated in **Fig. 4B**.

**[0162]** The calculation of the amount of circle segment radius expansion of the *BFBCE* needed to define to *MAAF* is made at the midpoint of the mesiodistal width of either maxillary central, $TMP_1$ in **Fig. 4C**, which is the intersection with *BFBCE* of circle $C_2$ in **Fig. 7C**. The tooth is placed on the maxillary contact arch form equation *MAAF* such that the mesial contact point of the tooth is on intersection of the midline *ML* and the maxillary contact arch form *MAAF* (**Fig. 4C**). The *MAAF* is defined as follows with respect to upper laterals and centrals:

$$MAAF = BFBCE + \Sigma\frac{P_{3x} - P_{2x}}{(t)\,(Avg)} + Clearance$$

where:

$t$ = number of teeth,
$Avg$ = 2 (for midpoint).

**[0163]** The *CGMRAF* coincides with the *BCBFE* as shown in **Fig. 4B**.

**[0164]** For the maxillary cuspids, the cusp tips are placed on some smooth arch between the *MAAF* and the *CGMRAF*. Preferably, their tips are placed on the *BFBCE* expanded by the average of the distances therefrom to the incisal tip of the lateral and to the buccal cusp tips of the first maxillary bicuspids.

**[0165]** The information from the prescription 27 from the orthodontist 14 is retrieved to determine which maxillary anterior vertical occlusion method has been selected, such as Roth or, Rickets occlusion, or the preferred method wherein the maxillary cuspids will extend a distance $CR_{U3}$ equal to 0.67 of the cuspid rise *CR* below the occlusal plane *MOC*, laterals extend a distance $CR_{U2}$ equal to 0.33 of the cuspid rise *CR* below the plane *MOC*, and the centrals extend a distance $CR_{U1}$ equal to 0.50 of the cuspid rise *CR* below the plane *MOC*:

**[0166]** The elected horizontal occlusion is selected, preferably, the horizontal tooth placement proceeds by calculating the positions of the teeth to provide the horizontal occlusion, a distance is calculated from *LIMOC* to *ICP* for the maxillary centrals and the laterals. This distance is referred to as the maxillary anterior offset *MAO*, thus:

$$ICP = \frac{X_2 + X_3}{2};\ \frac{Y_2 + Y_3}{2}$$

$$MAO = LIMOC_x - ICP_{x'}$$

The maxillary first bicuspid offset *MOB* is calculated as

$$MBO = P_{xx} - P_{xx'}$$

The maxillary tooth positions are then recalculated.

*Appliance Design Procedure (96)*

**[0167]** The appliance design procedure includes the steps of (1200) determining the location of the mandibular archwire plane relative to the calculated finish positions of the mandibular teeth, (1300) calculating the angle of each mandibular bracket slot relative to the mounting surface of the respective tooth, (1400) determining the location of the maxillary archwire plane relative to the calculated finish positions of the maxillary teeth, (1500) calculating the angle of each maxillary bracket slot relative to the mounting surface of the respective tooth, (1600) calculating the shape of the mandibular archwire and the slot in-out dimension of each mandibular bracket, (1700) calculating the shape of the maxillary archwire and the slot in-out dimension of each maxillary bracket, and (1800) calculating the contours of bracket placement jigs for each tooth.

(1200) *Mandibular Archwire Plane Step:*

**[0168]** The next step is (1200) to establish the position of the archwire plane for the mandibular teeth. The archwire plane can be located in an infinite number of vertical positions since the brackets and archwire will be designed to accommodate any chosen location. Since the overlap of the maxillary teeth is known, for labial bracket placement, the mandibular archwire plane is set to provide bracket clearance for the maxillary teeth in the finished occlusion. For lingual bracket placement, this consideration is given to the maxillary archwire plane instead, in step (1300) below.

**[0169]** Since the maxillary teeth do not pose a bracket interference dilemma with labial bracket placement. the brackets can be positioned for ease of placement, cosmetic considerations and gingival health. This applies to the mandibular bracket positioning where lingual bracket placement is used. Typically, these brackets are located more centrally than the brackets of the other arch.

**[0170]** More particularly, to establish the archwire plane, the selected vertical occlusion and respective vertical overlap from *MOC* for cuspids, laterals and centrals is recalled. Then, the buccal cusp height *BCH* is recalled for each bicuspid and molar. Next, the maximum *BCH* or anterior vertical overlap is chosen as the maximum vertical overlap *MVO*. Then, a distance equal to the *MVO* is measured downward from the *MOC*. Finally, half of the bracket height (typically 3.0 mm) plus an additional 0.75 mm is added for occlusal clearance. This defines the mandibular archwire plane *MAWP*. This places brackets as occlusal as possible with an 0.75 mm clearance from the worst case from the maxillary occlusion.

*(1300) Mandibular Slot Inclination Step:*

**[0171]** Once the archwire planes have been defined with respect to the teeth, (1300) the angle between the bracket mounting surface of the teeth and archwire plane is determined. This angle minus 90° is the facial torque or inclination angle to be formed into the brackets. This also defines the bracket slot placement height which is the distance from the top of the incisal edge to the archwire plane. This distance is calculated perpendicular to the archwire plane.

**[0172]** Slotless bracket bodies have now been positioned appropriately. A smooth archwire is then designed such that it will pass through the bodies of the brackets. The archwire must not cut too deeply into the bracket or pass even partially outside the face of the brackets. Brackets are chosen having different heights according to need. Without modifying buccal tube assemblies, standard bracket distances from the tooth surface to the center of the slot may be used as seed values. The archwire equation is then mathematically derived from cubic spline and tangential circle techniques as previously described. Both archwires are developed similarly.

**[0173]** Bracket angle determination (1300), more particularly, is achieved by taking the intersection of the *MAWP* and labial (buccal) surface of each mandibular tooth in the case of labial appliances, and the intersection of the *MAWP* with the lingual surface of each tooth in the case of lingual appliances. Then, circles are constructed with centers at the intersections and with diameters that represent the occluso-gingival (vertical) dimensions of the bracket bonding pad (typically 3.0mm). Then, *X*, *Y* coordinates of the circle intersections with labial (buccal) tooth surface are taken, and, with the

equations:

$$R^2 = (X_1 - h)^2 + (Y_1 - K)^2$$

$$Y_2 = mX_2 + b_2$$

$$Y_3 = mX_3 + b_3$$

**[0174]** The slopes between the points of intersection are calculated to produce the facial inclination *angle FIA.*:

| | |
|---|---|
| $h,k$ = | coordinates of circle center |
| $X_1, Y_2, b_2$ = | definition of first line segment |
| $X_3, Y_3, b_3$ = | definition of second line segment |

**[0175]** Then, as illustrated in **Fig. 8A** for labial appliances. x/2 radians are then subtracted to produce the slot inclination angle *SIA*:

$$FIA = \frac{Y_2 - Y_3}{X_2 - X_3}$$

$$SIA = FIA - x/2$$

*(1400) Maxillary Archwire Plane Step:*

**[0176]** The next step is (1400) locating the maxillary archwire plane as illustrated in diagram of **Fig. 8**. For the maxillary centrals, this involves finding the vertical distance from incisal edge to point $P_4$. The smallest value is selected and divided by two to produce the slot placement height for the maxillary centrals. For terminal maxillary bicuspids the vertical distance from buccal cusp to point $P_4$ is found. The smallest value is selected and divided by two. This produces the slot height *SPH* for the terminal maxillary bicuspids.

**[0177]** For maxillary centrals, the *Y* value of *FIMOC* is subtracted from the *Y* value for the slot placement height *SPH*. This is the distance from *MOC* to the slot centerline. For terminal maxillary bicuspids, the *Y* value of *MOC* is subtracted from the *Y* value for the slot placement height *SPH*. This is the distance from *MOC* to the slot centerline. Then, the *SPH* for the terminal bicuspid from *SPH* for the maxillary centrals. This is elevation change DH of the maxillary archwire relative to the *MOC* from the centrals to the terminal maxillary bicuspids. The elevation of the maxillary archwire *MXAWP* from the *MOC*, or archwire height *AHT* on each tooth, is calculated as

$$AHT = K + DH + SPH - MOC_Y$$

+ *Vertical overlap from* where *K* is the conversion factor from Table 2.

TABLE 2

| Tooth Type | Non- Extraction | Extraction (e.g. 2nd Bicuspid) |
|---|---|---|
| Maxillary Central | 0.0 | 0.0 |
| Maxillary Lateral | -0.19 | -0.23 |
| Maxillary Cuspid | -0.42 | -0.62 |
| Maxillary First Bicuspid | -0.68 | -1.00 |
| Maxillary Second Bicuspid | -1.00 | NA |
| Maxillary First Molar | -1.32 | -1.46 |

*(1500) Maxillary Slot Inclination Step:*

[0178] Once the archwire plane is determined, (1500) the slot inclination angle *SAI* for each of the maxillary tooth brackets is determined in a manner similar to the slot inclination determination step for the mandibular brackets (1300) by first finding the intersection of the maxillary archwire plane *MXAWP* with the labial or buccal surface of each maxillary tooth. Then, circles are described, for each maxillary tooth, having centers at this intersection point and having diameters equal to the occluso-gingival, or vertical, dimensions of the bracket bonding pad, which is typically 4.0 mm. From these circles, *X,Y* coordinates of the intersections of the circles with the labial or buccal tooth surface are found, as follows:

$$R^2 = (X_1 - h)^2 + (Y_1 - k)^2;$$
$$Y_2 = mX_2 + b_2;$$
$$Y_3 = mX_3 + b_3$$

Then, as illustrated in **Fig. 8A**, x/2 radians are them subtracted to produce the slot inclination angle *SIA*:

$$FIA = \frac{Y_2 - Y_3}{X_2 - X_3}$$

$$SIA = FIA - x/2$$

*(1600) Mandibular Archwire and Slot Depth Step:*

[0179] The next step, is (1600) to determine the mandibular archwire and bracket in-out dimension. First, the circle segment of the *BFBCE* with which the *ICP* of the right central is associated is determined, as illustrated in **Fig. 8D**. Then, the incisal center point and circle segment center point plane *ICPCDCPP* is created normal to the arch planes. An incisal center point line *ICPL* is struck that will pass through the *ICP* and a particular circle segment center point *CSCP* associated with the tooth. Then the Pythagorean distance *PD* from *CSCP* to *ICP* is determined. Then, viewing the tooth in the *ICPCSCPP*, as illustrated in **Fig. 8C**, a line *NL* is struck normal to the *BFBCE* plane through the *ICP*, which is the intersection of *CLA* and *BFBCE*. Next, still viewing the tooth in this plane, the intersection point *XP* of *NL* and *MAWP* is determined.

[0180] Still viewing the tooth in the *ICPCSCPP*, the *X* distance *XD* to the labial surface of the tooth from the *XP* is determined, and *PD* is added to *XD* and the lower limit of the bracket slot *LLBS*. The *LLBS* is a distance associated with the particular bracket that will be placed on this tooth. It is the deepest slot allowable for that bracket. Then, the lower limit *LL* is calculated as

$$LL = PD + XD + LLBS$$

Similarly, *PD* is added to the *XD* and the upper limit of the bracket slot *ULBS*. The *ULBS* is also a distance associated with the particular bracket that will be placed on this tooth. It is the shallowest slot allowable for that bracket. The, the upper limit *UL* is calculated as

$$UL = PD + XD + ULBS$$

[0181] Then, viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *LL* distance, *X* and *Y* points, $AWLL_{X,Y}$, are determined relative to an origin at the intersection of *BFBCE* and the mandibular midline *ML*. Then, viewing the mandibular occlusion in a plan view and moving out along the *ICPL* from its *CSCP* by the *UL* distance, *X* and *Y* points. $AWUL_{X,Y}$ are determined relative to the intersection of *BFBCE* and the mandibular midline *ML*. Then, the midpoint of $AWLL_{X,Y}$ and $AWUL_{X<Y}$ is found and steps through are then repeated for all mandibular teeth.

[0182] Then, the average mid-point and distance from right to left is calculated to force mandibular archwire symmetry:

$$S_X = MP_X + \frac{PR_X - PL_X}{2}$$

$$S_Y = MP_Y + \frac{PR_Y + PL_Y}{2}$$

The smoothest curve *SC* that will pass between all $AWLL_{X,Y}$ and $AWUL_{X,Y}$ points is then determined, as illustrated in **Fig. 4E.**

**[0183]** Preferably, it has no inflection points. If there are one or more inflection points, a logical alternative bracket solution will be derived based upon where the inflection occurred.

*(1700) Maxillary Archwire and Slot Depth Step:*

**[0184]** The next step, is (1700) to determine the maxillary archwire and bracket in-out dimension. As with the mandibular determination step (1600), the circle segment of the *BFBCE* with which the *ICP* of the right central is associated is determined. The step is similar to that for the mandibular slot in-out dimension calculation of **Figs. 4E** and **8C**, except that the maxillary centrals and laterals are associated with the *MAAF* rather than the *BFBCE*, the maxillary cuspids are associated with *MCAF*, and teeth posterior to the cuspid are associated with the *BFBCE*.

**[0185]** The bracket slot cutting is described in the discussion of step (3000) below.

*(1800) Placement Jig Design Step:*

**[0186]** The information necessary for the design of bracket placement jigs to aid the orthodontist in positioning the brackets in their proper positions on the individual teeth is now available. The design of the placement jigs is carried out in the software associated with the jig manufacturing step (3500) described below, following a loading of the appropriate files with the necessary data from the calculations described above into the manufacturing control computer 30c.

*(97) Appliance Manufacturing Procedure*

**[0187]** The appliance manufacturing procedure (97) includes the steps of (3000) manufacture of the custom brackets, (3200) manufacture of the custom archwires and (3500) manufacture of custom placement jigs for placement of the custom brackets on the patient's teeth. These steps are described in detail below for the embodiment in which all of the manufacturing is carried out at the appliance design facility 13.

*(3000) Bracket Manufacturing Step:*

**[0188]** The bracket manufacturing step (3000) produces the custom brackets, preferably by selecting bracket blanks and cuttings a torque slot in the bracket for the archwire 64.

**[0189]** The computer 30c loads the data for each bracket from the patient data file 36.

**[0190]** For each tooth and bracket, as a default or initial selection, low profile brackets are assumed. Then, the slot angle *FAI* and the slot in-out dimension *IO* are read. Also, the radius of the archwire at the tooth midpoint is determined.

**[0191]** Then, a main CNC program is created and the program loops to generate the code for the cutting of each bracket, beginning with the calculation of the variables for the bracket, assigning the variables for each bracket to set the cutting of the slot at the appropriate angle by rotating the bracket support 73 and setting the cutter 77c to a cooperating height *Z* and horizontal *X* position. If the position of the slot lies outside of the area of the bracket, a bracket of the appropriate higher profile is called for by the program, and loaded, either automatically or by an operator. The code is then generated to control the path of the cutter in the *Y* direction to cut the archwire radius in the slot bottom.

**[0192]** The CNC code is preferably downloaded to an NC controller and the brackets are formed by the cutting of the slots in the series of bracket blanks, and (3080) a report is written.

*(3200) Archwire Manufacturing Step:*

**[0193]** The archwire manufacturing step (3200) produces the archwire 64, that is symmetrical about its archwire midline *AML*, having the appropriate terminal leg span *TLS*, formed of a series of circle segments.

**[0194]** The manufacturing control computer 30c generates a CNC code to operate the wire forming machine 40. The program begins by opening files from the calculated patient data 36 and reading the wire alloy and the wire cross-section prescribed, and an array of data that contains a series of *j* sets of data including the radius and sector length of each circle segment of which the archwire curve is formed, and the calculated total cumulative archwire length. To the archwire equation, a radii and sector lengths are added to produce a one half inch (12.5mm) of straight segment at each end of the wire to form parallel terminal leg extensions. Then, calculating the cumulative slopes and sector lengths of

the wire along the equation, the terminal leg span *TLS* is calculated.

[0195] The slopes of the wire equation describing wire behavior are calculated by: (1) computing the coefficients of a parabola. (2) filling the first point of a slope array, (3) filling the intermediate points of the slope array, and (4) filling the last point of the slope array. Then, the vertical displacement of the bending lever arm *LA* between the contact points of the roller 70b with the wire 69 and the contact point of the rollers 68 with the wire 69 is determined for each circle segment of the archwire equation, and data added to the array.

[0196] Then, temporary variables are defined for the sector length, lever arm displacement, radius and terminal leg span across the straight segments of the archwire, the controller card 65 of the computer 30c is initialized, the controller base address is set, and default parameters are set. Then, a sequential series of sector lengths and lever arm displacements are sent respectively (1) through the circuits 66a and 67a to the drive of the feed rolls 68, and (2) through the circuits 66b and 67b to the anvil assembly 70.

[0197] Then the lever arm displacement is zeroed and the wire leg location is read by the sensor 71. This reading converted to a numerical value in the computer 30b and any difference in the actual measured terminal leg span and the desired terminal leg span *TLS* is calculated. If the difference is out of tolerance, a correction is made and another wire is formed.

*(3500) Jig Manufacturing Step:*

[0198] The jig manufacturing step (3500) produces bracket placement jigs custom designed for each tooth to aid in the placement of the custom designed brackets in the proper positions on the teeth so that the custom designed archwire will, when installed in the custom designed and custom placed brackets, move the teeth to their calculated finish positions.

[0199] The information necessary for the design of the custom placement jigs is contained in the patient data file and from the calculations made in the appliance design procedure (96) and in the tooth profile data rile of digitized information reed in step (500), in the illustrated embodiment of the invention. The design of the custom jigs involves, primarily, an assembly of the information already generated, and, in the preferred embodiment, takes place in the course of generating the code for control of the NC controlled manufacturing equipment 41 that produces the jigs.

[0200] In the preferred and illustrated embodiment, the jig manufacturing equipment 41 is a standard CNC mill equipped with a small carbide endmill tool of, for example, 0.5 mm (0.020 inches) in diameter (**Fig. 1F**). The jigs themselves 82 are made from circular ABS plastic wafers 83 of approximately 2.5 cm (one inch) in diameter and approximately 1.0 mm (0.040 inches) in thickness, though considerable variation in size is acceptable.

[0201] The jig manufacturing step (3500), begins with the execution of a program or routine in the manufacturing computer 30b and the input of parameters identifying the patient or case. Upon beginning of the execution of the program, the file of patient data 36 generated in the tooth position calculation and analysis procedure (95) and the appliance design procedure (96) is opened and information is read for each tooth, as illustrated in the diagram of Fig. 91, in relation to a tooth profile *PF*. The variables read are (a) the intersection of the archwire plane and the labial (or lingual, if prescribed) surface of the tooth *TS*, which is in the form of a pair of *X,Y* coordinates $TS_{X,Y}$ in the tooth profile vertical-labial/lingual plane, (b) the slot in-out dimension *Elan* or *10*, (c) the type of bracket, which provides access to the appropriate place in a lookup table of bracket dimensions, such as bracket base thickness *BRel* and bracket pad height *BPH*, and (d) the torque slot width, 0.018 or 0.022 from the prescription.

[0202] Then, the bracket data file is opened and the bracket base thickness read, as illustrated in **Fig. 9J**.

[0203] A CAD program file containing the tooth profiles $PF_i$ is loaded. The profiles *PF*, as illustrated in **Fig. 3C**, are made up of a series of closely spaced points in the profile plane, each represented by *X,Y* coordinates, connected by straight line segments to define the profile curve *PF*. The endmill tool diameter *Endmill* is also entered, which must be less than the archwire diameter or archwire slot width (0.018 or 0.022). Constants arc declared, including the diameter of the jig blank 83, the cut clearance on the outside of the jig, the number of loops, set at 23, and the counter initial settings.

[0204] Then, the CNC P-code is generated for each tooth.

[0205] This is followed by creating the profile and bracket clearance compensation tool paths *ITP* and *BCTP*, respectively. This involves the creation of an initial inside tool path line *IITP* made up of a series of straight line segments, one parallel to each of the line segments of the tooth profile curve, spaced a distance equal to the tool radius on the inside of the profile curve, as illustrated in **Fig. 9K**. the creation of an initial bracket base compensation tool path line *IBCTP* made up of a series of straight line segments, one parallel to each of the line segments of the tooth profile curve, spaced a distance equal to the bracket base dimension minus the tool radius outside of the profile curve, and (3600) creation of the final bracket base compensation tool path *(d)* to cut from the inside tool path line to the base compensation line at the top of the bracket base pad to cut off the jig at the bottom of the pad, as illustrated in **Fig. 9M** ("top" and "bottom" being used as an example for the lower teeth, and being opposite for the upper teeth).

[0206] Next, the archwire slot tool path *ASTP* is created, which can be understood from the sequence set forth in the

flowchart with reference to the diagrams of Figs. 9N, 9O and 9P. Then, a reference tool path *RefP* is created on an image of a jig blank 83, as illustrated in Fig. 9Q, and with reference to it. the outside jig boundary cutout *CTP* is added as illustrated in Fig. 2R, and (3620) the actual tool path *TP* is then generated as illustrated in Fig. 9S.

[0207] Then, (3625) the CNC machine code is generated, as illustrated in the detailed flowchart of Fig. 2Z-6, and written to the output file. Then, (3630) the variables are reset. (3635) the final results are displayed, and (3640) the program loops back to substep (3560) until all of the bracket jig code have been generated. Then, (3645) the completed CNC file is sent to the controller of the CNC mill and a pallet of wafers 83a (Fig. 1F) is cut into a set of bracket placement jigs 82. An example of one of the jigs is illustrated in Figs. 9T through 9W.

## Claims

1. A method of fabricating a custom orthodontic appliance to position teeth of a patient to preferred finish positions in the mouth of the patient, the method comprising the steps of measuring anatomical shapes from the mouth of the patient, and producing therefrom digitized anatomical shape data including <u>three dimensional</u> tooth shape data representing the shapes of individual teeth of the patient; deriving an <u>ideal</u> dental archform by processing the digitized anatomical shape data with a digital computer programmed to produce a digitized mathematical archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical shape data <u>and</u> the digitized mathematical archform model to mesiodistally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth; designing a custom orthodontic appliance with the computer from the digitized three dimensional tooth shape data, the established appliance connection points and the derived tooth finish positions, such that the custom orthodontic appliance has an appliance configuration dimensioned to interconnect the teeth at their respective connection points with the teeth in the derived tooth finish positions; producing machine readable control signals containing geometric information correlated to the results of the appliance designing step; and automatically fabricating a custom orthodontic appliance with a machine responsive to the machine readable control signals to shape the appliance according to the geometric information contained in the control signals so as to form the custom orthodontic appliance having the designed appliance configuration.

2. A method as claimed in claim 1 wherein the teeth include mandibular teeth and maxillary teeth and wherein: the anatomical shape measuring step includes the steps of measuring the lower jaw of a patient and producing thereby digitized data of lower jaw shape, and measuring mandibular and maxillary teeth of the patient and producing thereby digitized data of individual mandibular and maxillary tooth shape; the archform deriving step includes the step of deriving with the computer a mandibular skeletal archform from the digitized lower jaw shape data; and the tooth finish position deriving step includes the step of deriving tooth finish positions from the tooth shape data and the derived mandibular skeletal archform to arrange the teeth with respect to the mandibular skeletal archform.

3. A method as claimed in claim 2 wherein each tooth has a crown, a root and a long axis extending generally vertically through the centre of the crown, intersecting a gingival centre point where the crown meets the root, and wherein: the lower jaw measuring step includes the step of digitizing data points defining a mandibular trough in which mandibular tooth roots are to be confined; the mandibular skeletal archform deriving step includes the step of fitting a smooth continuous mandibular trough equation to the digitized mandibular trough data points and producing a digitized representation of the mandibular trough equation; the tooth finish position deriving step includes deriving positions which centre each mandibular tooth by placing the long axis thereof approximately on the mandibular trough equation near the gingival centre point of the tooth, and which place the tips of the mandibular teeth on a smooth continuous curve derived by adjusting the mandibular trough equation; and the appliance designing step includes defining the appliance configuration by a series of digital values derived from the smooth continuous curve.

4. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing data of the shape of the lower jaw of the patient by digitizing boundary points corresponding to boundaries of the patient's cortical bone and, the archform deriving step includes the step of deriving from the digitized data a skeletal archform mathematically representing the shape of the patient's cortical bone by a smooth continuous equation derived from the digitized boundary points.

5. A method as claimed in claim 4 wherein the smooth continuous equation is a cubic spline equation through points related to the digitized boundary points.

6. A method as claimed in any preceding claim wherein the archform deriving step comprises the step of defining a curve based on the digitized anatomical shape data and smoothing the curve by a best fit statistical method to produce smooth continuous archform equation, the finish position deriving step and the appliance configuration designing step being based at least in part on the archform equation.

7. A method as claimed in any preceding claim further comprising the steps of digitally representing the derived archform by an archform equation in the computer; representing the archform equation by a series of successively tangent circle segments; wherein the appliance designing step includes the step of designing an arcuate appliance at least in part in accordance with a series of digital values representing circle segment lengths and radii derived from the circle segments of the archform equation and, the appliance fabricating step includes the step of converting the segment lengths and radii to a series of commands to produce the control signals and, in response to the signals, sequentially forming the appliance to a radius corresponding to each segment length thereof in response to the signals to conform to the designed appliance configuration.

8. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing the distances between mesial and distal contact points for each tooth to define mesial-distal widths for each tooth; the tooth finish position deriving step includes the step of deriving tooth finish positions to place adjacent mesial and distal contact points of adjacent teeth in mutual contact to form a tooth placement arch conforming in shape to the derived archform and approximately equal in length to the sum of the mesial-distal widths of the teeth placed thereon; and the appliance designing step includes the step of designing the appliance configuration in part from the mesial-distal widths and tooth placement arch.

9. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing, for each tooth, tooth profile data in the form of a series of digitized data points representing the shape of the surface of the tooth at least along a profile thereof extending generally vertically and labial-lingually; the connection point establishing step includes the step of locating an appliance connection point on the surface of each of the plurality of teeth along a profile thereof; and the appliance designing step includes the step of designing, from the series of digitized data points representing the shape of the surface of the teeth, the established connection points and the derived tooth positions.

10. A method as claimed in any preceding claim wherein the archform deriving step includes the steps of comparing corresponding contralateral points on opposite sides of the archform and, on the basis of the comparison, calculating a modified archform that is laterally symmetrical about its centre; and designing the appliance based at least in part on the modified archform.

11. A method as claimed in any preceding claim wherein the measuring step includes the step of digitizing data of points on labial and lingual surfaces of each of a plurality of the teeth of the patient, and the method further comprises deriving from the digitized labial and lingual surface data a digital representation of the orientation of a crown long axis of each tooth with respect to the points and calculating finish positions of the teeth from the digitized data and the digital representations of the crown long axes of the teeth, the calculated finish positions including preferred crown long axis orientations.

12. A method as claimed in claim 11 further comprising the steps of calculating the preferred crown long axis orientations for a plurality of patients and producing a record of the calculated preferred crown long axis orientations; recording personal data of each of the patient, correlating the personal data with the calculated preferred crown long asis orientations and classifying the patients in population groups on the basis of the correlation; and producing a statistical record of preferred crown long axis orientations for patients of the population groups.

13. A method as claimed in any preceding claim wherein the appliance designing step includes the step of designing appliance placement jig configurations from the tooth shape data, each having a jig surface that will conform to the surface of a respective tooth for facilitating the location of the connection point thereon and the connection of the appliance thereto; the control signal producing step includes the step of producing the control signals at least in part in accordance with the designed appliance placement jig configurations; and the appliance fabricating step includes the step of automatically fabricating appliance placement jigs with the machine in response to the control signals to conform to the designed placement jig configurations.

14. A method as claimed in claim 13 wherein the appliance placement jig configuration designing step comprises the steps of calculating, from the digitized tooth shape data and defined connection points, jig geometry defining a jig

locating surface that conforms to a unique portion of the external surface of the crown of a tooth, and defining an appliance engaging surface having the same location relative to the jig locating surface as the unique portion of the external surface has to the connection point on the tooth, so that, the machine, when operated in response to the control signals, will form a jig that, when fitted on the tooth, will position and orient an appliance engaged thereby at the connection point of the tooth for connection thereto.

15. A method as claimed in claim 14 wherein the connection point defining step includes the step of calculating the connection points from the digitized tooth shape data; and the jig geometry calculating step includes the step of defining the appliance engaging surface such that the location relative to the jig locating surface is the same as that of the unique portion of the external surface to the calculated connection point on the tooth.

16. A method as claimed in either claim 14 or claim 15 wherein the appliance includes a plurality of brackets, one for connection at each connection point to a tooth, each bracket having an archwire receiving slot therein; the appliance configuration design includes bracket shape data including a digital representation of the position and inclination of the slot in the bracket; and the jig geometry calculating step includes the step of defining the appliance engaging surface to include a part thereof that will align with the slot of the bracket when the bracket is engaged thereby.

17. A method as claimed in claim 16 wherein the appliance designing step includes the step of calculating bracket design to accommodate an archwire of arcuate shape.

18. A method as claimed in either claim 16 or 17 wherein the appliance designing step includes the step of selecting, from a plurality of bracket blanks, an optimum blank for the manufacture of the bracket in accordance with slot digital representation.

19. A method as claimed in any preceding claim wherein the measuring step includes the step of measuring the shapes of individual upper and lower teeth and the shape of the lower jaw of the patient and producing thereby digitized upper and lower tooth data and lower jaw shape data, the tooth shape data including data of the incisal tips of the lower anterior teeth and buccal cusp tips of lower posterior teeth and central ridge or marginal ridge locations of upper posterior teeth; the tooth finish position deriving step includes the steps of deriving a tooth-bearing lower jaw configuration based on assembly of the lower teeth along the lower arch configuration with adjacent teeth in contact with each other and the lower arch configuration; vertically adjusting each lower tooth such that the incisal tips of the lower anterior teeth and buccal cusp tips of the lower posterior teeth are in substantially the same occlusal plane and are inclined at controlled angles of inclination; adjusting the tooth-bearing lower arch configuration to provide a finished tooth bearing lower jaw configuration by labially-lingually positioning the lower teeth to place the incisal and buccal cusp tips thereof in a smooth arch in the occlusal plane with adjacent teeth in contact with each other; and deriving a tooth-bearing finished upper tooth configuration in which the posterior teeth have their central grooves or marginal ridges lying horizontally on the finished tooth bearing lower jaw configuration and vertically on the occlusal plane; the anterior teeth have their incisal tips positioned below the occlusal plane to achieve predetermined overlaps and are horizontally labially offset from the finished tooth bearing lower jaw configuration so as to establish a predetermined clearance between the lower anterior teeth lingual faces and the labial faces of the lower anterior teeth; the appliance designing step includes the step of calculating a bracket configuration for individual upper and lower tooth brackets including the angle and depth of a slot in each bracket, and calculating and archwire shape for upper and lower archwire, based upon the calculated finished tooth positions, predetermined upper and lower archwire planes, the tooth shapes, and the connection positions and, the appliance fabricating step includes the steps of fabricating upper and lower archwires to conform to the calculated archwire shapes; and fabricating brackets to conform to the calculated bracket configurations.

20. A method as claimed in any preceding claim further comprising the steps of providing criteria describing the distances of the individual teeth from the pivot axis of the lower jaw; wherein the tooth finish position deriving step includes the steps of calculating from the criteria and the tooth shape data a component of cuspid rise; and vertically adjusting the upper and lower cuspids such that their cusp tips are respectively below and above the occlusal plane a distance that has a predetermined relationship to the calculated cuspid rise.

21. A method as claimed in claim 20 when dependent on claim 19 wherein the tooth-bearing finished upper tooth configuration deriving step includes deriving the configuration in which the upper anterior teeth have incisal tips positioned below the occlusal plane so as to achieve predetermined overlaps that have a predetermined relationship to the calculated cuspid rise.

22. A method as claimed in either claim 20 or claim 21 wherein the cuspid rise component calculating step includes the steps of identifying occluding pairs of respective upper and lower posterior teeth of the patient, and determining for each pair from the digitized tooth shape data a vertical distance from the highest extent of the lower tooth of the pair to the lowest extent of the upper tooth of the pair when the jaws are in a closed position; adjusting each determined vertical distance by a factor proportionally related to a distance of each pair from the pivot axis, and selecting the largest adjusted vertical distance calculating, from the digitized data, finish positions of the mandibular teeth of the patient at which highest points thereon are at vertical positions on an approximately flat occlusal surface; and calculating finish positions of the upper and lower cuspids of the patient extend respectively below and above the occlusal surface.

23. A method as claimed in any preceding claim further comprising the steps of providing an orthodontic appliance designing and manufacturing system including a data input sub-system for the digitizing input data of measured anatomical shapes and generating input signals carrying the digitized input data, a data processing sub-system for processing the digitized input signals and generating, in response thereto, output signals carrying the control signals and an appliance hardware manufacturing sub-system, including the fabricating machine, for fabricating, in response to the output signals, a custom orthodontic appliance for the treatment of the patient by moving the teeth of the patient to the preferred finish positions; generating, with the data processing sub-system, from the derived archform, output signals for operating the appliance hardware manufacturing sub-system to fabricate the custom orthodontic appliance; and fabricating, with the appliance hardware manufacturing sub-system, in response to the output signal and in accordance with the control signals the custom orthodontic appliance of the custom configuration.

24. A method as claimed in claim 23 wherein the custom orthodontic appliance includes an archwire having an arcuate shape that is mathematically related to the mandibular trough skeletal archform; the appliance hardware manufacturing sub-system includes a wire bending apparatus responsive to signals carried by the output signal; and the output signal includes a series of control signals for operating the wire bending apparatus to feed a wire and to bend the fed wire into the custom archwire configuration for connection of the archwire to the teeth of a jaw at a respective connection points.

25. A method as claimed in claim 24 wherein the digitized input data contains information from which the connection point of the appliance and slope of the surface at the connection point can be derived; the custom orthodontic appliance includes a plurality of brackets, one for each tooth connection point, each having a base securable to the respective connection point, and each having an archwire slot connectable to the archwire; the appliance hardware manufacturing sub-system includes a bracket fabricating apparatus responsive to control signals carried by the output signal; and, the output signal includes a series of control signals for operating the bracket fabricating apparatus to fabricate each bracket with the archwire slot positioned with respect to the base to support and orient a point on the archwire with respect to the connection point of the respective tooth to transfer force therebetween to urge the tooth toward its finish position.

26. A method as claimed in claim 25 wherein the digitized input data contains information of a contour on the surface of the tooth; the custom orthodontic appliance includes a bracket placement jig for each bracket having a surface for uniquely positioning the jig with respect to the surface of the tooth and for positioning the bracket thereon at the connection point thereof; the appliance hardware manufacturing sub-system includes a bracket placement jig fabricating apparatus responsive to control signals carried by the output signal; and, the output signal includes a series of control signals for operating the bracket placement jig fabricating apparatus to fabricate the bracket placement jig.

27. A method as claimed in either claim 25 or claim 26 wherein the appliance fabricating step includes the steps of providing a plurality of bracket blanks; and forming a bracket from the bracket blank by forming an archwire slot in each of the bracket blank such that each slot will lie in an archwire plane when the bracket is mounted on the connection point of a tooth with the tooth in its derived finish position.

28. A method as claimed in claim 27 wherein the archform deriving step includes the step of deriving from the digitized data a skeletal archform mathematically representing the shape of the patient's cortical bone by a smooth continuous equation derived from digitized boundary points corresponding to the boundaries of the patient's cortical bone and representing the archform equation by a series of successively tangent circle segments the bracket slot cutting step includes the step of forming the slot to a depth defined by the intersection of the archform equation with the bracket, when the bracket is mounted on the connection point of a tooth with the tooth in its derived finish position;

and the bracket slot cutting step includes the step of forming the slot to a slot bottom curvature of the radius of the intersecting circle segment of the archform equation.

29. A method as claimed in any preceding claim wherein to provide optimal spacing thereof from the gums of a patient and clearance with teeth of the opposite jaw of the patient, the connection position establishing step includes the steps of digitizing the geometry of parts of the appliance; calculating from the digitized tooth shape data, the relationships of points on the surfaces of teeth of the opposite jaws of the patient; calculating from the digitized data, locations on the surfaces of the teeth of one jaw of the patient at which the appliance is to be connected to provide optimal spacing thereof from the gums of a patient and clearance with teeth of the opposite jaw of the patient; and designing the appliance configuration in accordance with the calculated locations for connection of the appliance to the teeth of the patient.

30. A method as claimed in any one of claims 1 to 23 wherein the custom orthodontic appliance includes an archwire; the appliance designing step includes the step of deriving digital archwire shape data based at least in part on the derived archform; the control signal producing step includes the step of generating a wire shape control signal in response to the digital archwire shape data, such that, when communicated to an archwire former, the former will produce a custom orthodontic archwire based on the anatomical shapes from the individual patient's mouth; and forming a length of orthodontic archwire material into a controlled shape in response to the wire shape control signal to produce the custom archwire.

31. A method as claimed in claim 30 wherein the control signal producing step includes the steps of providing archwire material property data of the archwire material; and generating the wire bending control signal in response to the material property data of the archwire material.

32. A method as claimed in either claim 30 or claim 31 further comprising the steps of measuring an archwire span between two points on the produced custom archwire; calculating a design archwire span from the derived archwire shape data; comparing the measured archwire span with the design archwire span and signalling a result of the comparison; and generating the wire bending control signal in response to the signalled result of the comparison.

33. A custom orthodontic appliance fabricating apparatus comprising means (30,30a,33,43,50,57) for measuring anatomical shapes (20-24) from the mouth (18) of the patient (12) and producing thereby digitized anatomical shape data (26) including three dimensional tooth shape data representing the shapes of individual teeth of the patient, a digital computer (30b,30c) including program means for deriving an ideal dental archform from the digitized data (26) with a specially programmed digital computer (30b) to produce a digitized archform model that is at least in part dependent on the digitized anatomical shape data; deriving with the computer tooth finish positions from the digitized anatomical data (26) and the derived digitized ideal archform to mesio-distally space the teeth along the derived ideal dental archform and to position and orient the teeth relative to the derived ideal dental archform to positions and orientations based at least in part upon the three dimensional tooth shape data for the respective individual teeth; establishing an appliance connection point on each of a plurality of the teeth; designing, from the digitized tooth shape data, established appliance connection point and the derived tooth finish positions, an appliance configuration such that a custom appliance fabricated in accordance therewith is dimensioned to interconnect the teeth at the connection point with the teeth in the derived tooth finish positions, and producing machine code (42) containing geometric information correlated to the designed appliance configuration; and a machine (38,39,40,41) for automatically fabricating a custom orthodontic appliance (25) in response to the machine code (42) to shape the appliance (25), according to the geometric information so as to form the appliance (25) with the designed appliance configuration.

34. Apparatus as claimed in claim 33 wherein the fabricating machine (38) comprises an archwire former (40) including means (66-71) for forming a length of orthodontic archwire material (69) into a controlled shape in response to a wire shape control signal communicated thereto; and the program means including means for generating a wire shape control signal in response to the digital archwire shape data, such that, when the signal is communicated to the archwire former, the former will produce a custom orthodontic archwire (64) conforming to the anatomical shape of the individual patient's mouth (18).

35. Apparatus as claimed in claim 34 wherein the derived digital archwire shape data includes wire length data correlated to a length component of the derived digital archwire shape data and wire curvature data correlated to a curvature component of the derived digital archwire shape data that is a function of the length component; the wire

shape control signal includes a wire feed control signal carrying the wire length data and a wire bending control signal carrying the wire curvature data; the program means includes means for generating the wire feed control signal and means for generating a wire bending control signal and communicating the control signals to the archwire former; and the archwire former (40) includes means (68) for longitudinally feeding the orthodontic archwire material (69) in response to the wire feed control signal and means (70) for transversely bending the archwire material (69) fed by the wire feeding means (68) in response to the wire bending control signal and in synchronism with the feeding of the archwire material (69).

36. Apparatus as claimed in claim 34 wherein the digital archwire shape data is a digital representation of a connected series of wire segments, each having a length component and a curvature component; and the archwire former includes means for longitudinally feeding a series of lengths of the orthodontic archwire material corresponding to the respective wire length components in accordance with the wire length data and means (70) for bending each fed length of archwire material (69) to a curvature corresponding to the respective wire curvature component in accordance with the wire curvature data.

37. Apparatus as claimed in claim 36 wherein each wire segment is in the form of a circle segment with the length component thereof representing a tangential length of archwire material and with the curvature component thereof representing a constant radius of curvature of the material over the tangential length of the segment; and the feeding means (68) includes means for longitudinally feeding a series of tangential lengths of the orthodontic archwire material (69) and the bending means (70) includes means for bending each fed length of archwire segment to a constant radius in accordance with the wire curvature data.

38. Apparatus as claimed in claim 37 wherein the feeding means (68) is operative to sequentially feed a series of lengths of the archwire material equal to the length components of the circle segments, in response to the wire feed signal, along a longitudinal path; the bending means (70) includes a bending element (70b) moveable in response to the wire bending signal transverse to the path to impart a transverse bending deflection to the segment and a transverse position sensor for producing a feedback signal responsive to the deflection; and the computer (30b, 30c) includes means for modifying the wire bending control signal in response to the feedback signal to provide closed loop control of the bending element.

39. Apparatus as claimed in any one of claims 36 to 38 further comprising means for measuring an archwire span between points on first and last segments of the series of the produced custom orthodontic archwire (64); the program means including means for calculating a design archwire span from the derived archwire shape data; means for comparing the measured archwire span with the design archwire span and for storing the results of the comparison; and the program means being operative to generate the wire shape control signal in response to a stored result of the comparison.

40. Apparatus as claimed in any one of claims 36 to 39 wherein the program means includes means in communication with the wire shape control signal generating means for receiving material property data of the archwire material and for modifying the wire bending control signal in accordance with the property data to compensate for elastic properties of the material.

41. Apparatus as claimed in any one of claims 33-40 wherein the fabricating machine (38) comprises a bracket forming apparatus (39) including a holder (73) having means thereon for mounting a bracket blank (80) thereon for fabrication; means (75-77) for forming at least one surface of a bracket blank (80) mounted on the holder (73) in response to a machine control signal communicated thereto in response to the control signal including means (77) for shaping the bracket blank (80) mounted on the holder (73) to produce a bracket having a slot of a calculated geometric relationship to the mounting surface of the bracket base thereof.

42. Apparatus as claimed in claim 41 wherein each slot includes generally parallel upper and lower sides defining a slot inclination and includes a slot base at an end thereof nearest the bracket base defining a slot position; each calculated geometric relationship of a slot to the mounting surface of a bracket includes the slot inclination and a slot position relative to the mounting surface; the generated machine control signal carries machine control instructions for causing the forming means (75-77) to shape the bracket blank (80) to produce a bracket having a slot (80b) of the calculated slot inclination and slot position with respect to the mounting surface; the slot (80b) of each bracket is adapted to receive an archwire (64) having a custom curvature adjacent the tooth on which the bracket is to be secured; each calculated geometric relationship of a slot to the mounting surface of a bracket includes a slot bottom curvature conforming to the custom curvature of the archwire (64) adjacent thereto; and the generated machine

control signal carries machine control instructions for causing the forming means to shape the bracket blank (80) to produce a bracket having a slot of the calculated slot bottom curvature.

43. Apparatus as claimed in either claim 41 or claim 42 wherein the forming means (75-77) includes means (77) for cutting a slot (80b) in response to the control signal.

44. Apparatus as claimed in any one of claims 41 to 43 wherein the holder (73) and the forming means (75-77) are mounted on a stand (72); and the apparatus further comprises means (74) for angularly orienting the holder (73) with respect to the stand (72) and to the forming means (75-77), and means (75,76) for translating the shaping means (77) with respect to the stand (72) and to the holder (73), in response to the control signal.

45. Apparatus as claimed in any of claims 33 to 44 wherein the fabricating machine (38) comprises a jig former (41) including means (81) for forming a jig for positioning a custom orthodontic appliance on a tooth of a patient, including means (81) for shaping the contours of a surface of a blank of jig forming material (83) in response to a control signal communicated thereto; the measuring means (30,30a,33,43,50,57) includes means for providing a digitized record of the shapes of the teeth of a patient (12) and of the locations relative to the tooth shape record of appliance connection points on surfaces of the teeth; the program means includes means for calculating, from the digitized tooth shape and connection point record, jig geometry defining a jig locating surface that conforms to a unique portion of the external surface of the crown of a tooth, and defining an appliance engaging surface having the same location relative to the jig locating surface as the unique portion of the external surface has to the connection point on the tooth; and the generating means includes means for generating a machine control signal carrying machine control instructions for producing a jig (82) in accordance with the calculated jig geometry.

46. Apparatus as claimed in claim 45 wherein the appliance includes a plurality of brackets (80) one for connection at each connection point to a tooth; the apparatus further comprises means for providing digitized bracket shape data of an external surface of each bracket to be connected to a connection point; and wherein the jig geometry calculating means includes means for defining the appliance engaging surface of the jig to conform, in response to the digitized bracket shape data, to the established appliance geometry.

## Patentansprüche

1. Verfahren zur Herstellung eines individuellen kieferorthopädischen Apparats für die Bewegung der Zähne eines Patienten in gewünschte Endpositionen im Mund des Patienten, das folgende Schritte umfaßt: Vermessen der anatomischen Formen im Mund des Patienten und darauf aufbauend Gewinnen digitalisierter Daten zu den anatomischen Formen, einschließlich der die Formen der einzelnen Zähne des Patienten darstellenden dreidimensionalen Zahnformdaten; Ableiten einer idealen Zahnbogenform durch Verarbeiten der digitalisierten Daten zu den anatomischen Formen mit Hilfe eines Computers, der für die Erstellung eines zumindest teilweise von den digitalisierten Daten zu den anatomischen Formen abhängigen digitalisierten mathematischen Bogenform-Modells programmiert ist; Ableiten der Zahnendpositionen aus den digitalisierten Daten zu den anatomischen Formen sowie des digitalisierten mathematischen Bogenform-Modells mit Hilfe des Computers zur mesiodistalen Anordnung der Zähne auf dem abgeleiteten idealen Zahnbogen und zur Bewegung der Zähne in bezug auf den abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; Konstruktion eines individuellen kieferorthopädischen Apparats anhand der dreidimensionalen Zahnformdaten, der vorgegebenen Apparatfixierpunkte und der abgeleiteten Zahnendpositionen mit Hilfe des Computers, so daß der individuelle kieferorthopädische Apparat eine solche Auslegung erhält, daß eine Verbindung zwischen den Zähnen an ihren entsprechenden Fixierpunkten und den Zähnen in den abgeleiteten Zahnendpositionen besteht; Erzeugen maschinenlesbarer Steuersignale, die mit den Ergebnissen des Apparatkonstruktionsschritts korrelierende geometrische Informationen enthalten; und automatisches Fertigen eines individuellen kieferorthopädischen Apparats mit Hilfe einer Fertigungsanlage, die mittels maschinenlesbarer Steuersignale steuerbar ist und den Apparat entsprechend den in den Steuersignalen enthaltenen geometrischen Informationen formt, so daß der individuelle kieferorthopädische Apparat mit der zuvor konstruierten Konfiguration ensteht.

2. Verfahren nach Anspruch 1, bei dem unter dem Begriff Zähne sowohl die Unterkieferals auch Oberkieferzähne zu verstehen sind und bei dem der Schritt Vermessen der anatomischen Form die Schritte Vermessen des Unterkiefers eines Patienten und auf dieser Grundlage Gewinnen digitalisierter Daten zur Form des Unterkiefers sowie Vermessen der Unterkiefer- und Oberkieferzähne des Patienten und auf dieser Grundlage Gewinnen digitalisierter Daten zur Form der jeweiligen Unterkiefer- und Oberkieferzähne umfaßt; der Schritt Ableiten der Bogenform den

Schritt Ableiten einer Mandibularskelettbogenform aus den digitalisierten Daten zur Unterkieferform mit Hilfe des Computers umfaßt; und der Schritt Ableiten der Zahnendposition den Schritt Ableiten der Zahnendpositionen aus den Zahnformdaten und der abgeleiteten Mandibularskelettbogenform umfaßt, so daß die Zähne unter Berücksichtigung der Mandibularskelettbogenform angeordnet werden.

3. Verfahren nach Anspruch 2, bei dem jeder Zahn eine Krone, eine Wurzel und eine Längsachse aufweist, die im allgemeinen senkrecht durch den Mittelpunkt der Krone verläuft und sich mit einem Gingivamittelpunkt schneidet, in dem die Krone an die Wurzel angrenzt, und bei dem der Schritt Vermessen des Unterkiefers den Schritt Digitalisieren von Punkten von Daten umfaßt, die eine die Wurzeln der Unterkieferzähne einschließende Mandibularalveolenmulde definieren; der Schritt Ableiten der Mandibularskelettbogenform den Schritt Anpassen einer glatten stetigen Mandibularalveolenmuldengleichung an die digitalisierten Punkte der Mandibularalveolenmuldendaten und Gewinnen einer digitalisierten Darstellung der Mandibularalveolenmuldengleichung umfaßt; der Schritt Ableiten der Zahnendposition das Ableiten von Positionen umfaßt, durch die jeder Unterkieferzahn mittig ausgerichtet wird, indem dessen Längsachse approximativ auf die Mandibularalveolenmuldengleichung nahe dem Gingivamittelpunkt des Zahns angeordnet wird, und durch die die obersten Zahnpartien der Unterkieferzähne auf eine glatte stetige Kurve gebracht werden, die durch Anpassen der Mandibularalveolenmuldengleichung abgeleitet wurde; und bei dem der Schritt der Apparatkonstrution die Festlegung der Apparatkonfiguration mit Hilfe einer Reihe aus der glatten stetigen Kurve abgeleiteter digitaler Werte umfaßt.

4. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Daten zur Form des Unterkiefers des Patienten durch Digitalisieren den Grenzen der Kompakta des Patienten entsprechender Grenzpunkte und der Schritt Ableiten der Bogenform den Schritt Ableiten einer die Form der Kompakta des Patienten mathematisch darstellenden Skelettbogenform aus den digitalisierten Daten mit Hilfe einer aus den digitalisierten Grenzpunkten abgeleiteten glatten stetigen Gleichung umfaßt.

5. Verfahren nach Anspruch 4, bei dem die glatte stetige Gleichung eine kubische Spline-Funktion durch Punkte ist, die mit den digitalisierten Grenzpunkten in Beziehung stehen.

6. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Ableiten der Bogenform den Schritt Definieren einer Kurve auf der Grundlage der digitalisierten Daten zur anatomischen Form und Glätten der Kurve mit Hilfe eines statistischen Best-fit-Verfahrens zur Gewinnung einer glatten stetigen Bogenformgleichung umfaßt, wobei der Schritt Ableiten der Endposition und der Schritt Konstruktion der Apparatkonfiguration zumindest teilweise auf der Bogenformgleichung basieren.

7. Verfahren nach einem der vorstehenden Ansprüche, das zudem die Schritte digitale Darstellung der abgeleiteten Bogenform durch eine Bogenformgleichung mittels Computer; und Darstellung der Bogenformgleichung durch eine Reihe von einander berührenden Kreissegmenten beinhaltet; und bei dem der Schritt Konstruktion des Apparats den Schritt Konstruktion eines bogenförmigen Apparats zumindest teilweise in Übereinstimmung mit einer Reihe von digitalen Werten, die die Kreissegmentlängen und -radien darstellen, die ihrerseits aus den Kreissegmenten der Bogenformgleichung abgeleitet wurden, und der Schritt Fertigen des Apparats den Schritt Umwandeln der Segmentlängen und -radien in eine Reihe von Befehlen zur Gewinnung von Steuersignalen und, gesteuert durch diese Signale, schrittweises Formen des Apparats mit einem einer jeden Segmentlänge des Apparats entsprechenden Radius in Übereinstimmung mit der berechneten Apparatkonfiguration umfaßt.

8. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Entfernungen zwischen den mesialen und distalen Kontaktpunkten eines jeden Zahns zur Definition der mesial-distalen Breiten eines jeden Zahns; der Schritt Ableiten der Zahnendpositionen den Schritt Ableiten der Zahnendpositionen, wobei aneinander angrenzende mesiale und distale Kontaktpunkte benachbarter Zähne miteinander in Kontakt zu bringen sind, wodurch ein Zahnanordnungsbogen gebildet wird, der in bezug auf die Gestalt mit der abgeleiteten Bogenform übereinstimmt und etwa die gleiche Länge wie die Summe der mesial-distalen Breiten der darauf angeordneten Zähne aufweist; und der Schritt Konstruktion des Apparats den Schritt Konstruktion der Apparatkonfiguration teilweise anhand der mesial-distalen Breiten und des Zahnanordnungsbogens umfaßt.

9. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der für jeden Zahn gewonnenen Zahnprofildaten in Form einer Reihe digitalisierter Punkte von Daten, die die Gestalt der Zahnoberfläche zumindest entlang eines sich im allgemeinen senkrecht und labial-lingual erstreckenden Zahnprofils darstellen; der Schritt Vorgeben des Fixierpunktes den Schritt örtliches Zuweisen eines Apparatfixierpunktes auf der Oberfläche eines jeden einer Anzahl von Zähnen entlang dem Zahnprofil; und der Schritt Konstruktion

des Apparats den Schritt Konstruktion der vorgegebenen Fixierpunkte und der abgeleiteten Zahnpositionen aus einer Reihe die Gestalt der Zahnoberfläche darstellender Punkte digitalisierter Daten umfaßt.

10. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Ableiten der Bogenform die Schritte Vergleichen entsprechender einander gegenüberliegender Punkte auf einander gegenüberliegenden Seiten der Bogenform und auf der Grundlage dieses Vergleichs Berechnen einer modifizierten Bogenform mit seitlicher Symmetrie gegenüber ihrer Mittellinie sowie Konstruktion des Apparats zumindest teilweise auf der Grundlage der modifizierten Bogenform umfaßt.

11. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Digitalisieren der Daten von Punkten an den labialen und lingualen Flächen eines jeden Zahns einer Anzahl von Zähnen des Patienten umfaßt, und das des weiteren beinhaltet: Ableiten einer digitalen Darstellung der Ausrichtung einer Kronenlängsachse eines jeden Zahns in bezug auf die Punkte aus den digitalisierten Daten der labialen und lingualen Fläche sowie Berechnen der Endpositionen der Zähne anhand der digitalisierten Daten und der digitalen Darstellungen der Kronenlängsachsen der Zähne, wobei die berechneten Endpositionen bevorzugte Kronenlängsachsenrichtungen einschließen.

12. Verfahren nach Anspruch 11, das ferner die Schritte Berechnen der bevorzugten Kronenlängsachsenrichtungen für eine Anzahl von Patienten und Dokumentieren der berechneten bevorzugten Kronenlängsachsenrichtungen; Dokumentieren der Personendaten eines jeden Patienten, Zuordnen der Personendaten zu den berechneten bevorzugten Kronenlängsachsenrichtungen und Klassifizieren der Patienten in Populationsgruppen auf der Basis dieser Zuordnung; sowie Erstellen einer Statistik zu den bevorzugten Kronenlängsachsenrichtungen bei den Patienten der Populationsgruppen umfaßt.

13. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Konstruktion des Apparats den Schritt Konstruktion der Apparateinsetzhalterkonfigurationen anhand der Zahnformdaten umfaßt, wobei für jede Konfiguration eine Halteroberfläche vorgesehen wird, die mit der jeweiligen Zahnoberfläche übereinstimmt, wodurch die Festlegung der Anordnung des Fixierpunktes und die Fixierung des Apparats an der Zahnoberfläche erleichtert werden; der Schritt Erzeugen der Steuersignale den Schritt Erzeugen von Steuersignalen umfaßt, die zumindest zu einem Teil mit den konstruierten Apparateinsetzhalterkonfigurationen übereinstimmen; und der Schritt Fertigen des Apparats den Schritt automatische Fertigung der Apparateinsetzhalter entsprechend den Steuersignalen zur Gewährleistung der Übereinstimmung mit den berechneten Einsetzhalterkonfigurationen umfaßt.

14. Verfahren nach Anspruch 13, bei dem der Schritt Konstruktion der Apparateinsetzhalterkonfigurationen die Schritte Berechnen der Haltergeometrie anhand der digitalisierten Zahnformdaten und der definierten Fixierpunkte umfaßt, wobei eine Halteranlagefläche, die mit dem individuellen Abschnitt der Kronenaußenfläche eines Zahns übereinstimmt, und eine Apparatangriffsfläche, die hinsichtlich der Lage mit der Halteranlagefläche genauso übereinstimmt, wie der individuelle Abschnitt der Außenfläche mit dem Fixierpunkt am Zahn, definiert werden, so daß die Fertigungsanlage bei Steuerung anhand der Steuersignale einen Halter fertigt, der bei Einsatz am Zahn einen Apparat, auf den er am Fixierpunkt des Zahns zum Befestigen daran aufgesetzt wird, am Ort fixiert und ausrichtet.

15. Verfahren nach Anspruch 14, bei dem der Schritt Festlegen des Fixierpunktes den Schritt Berechnen der Fixierpunkte anhand der digitalisierten Zahnformdaten; und der Schritt Berechnen der Haltergeometrie den Schritt Festlegen der Apparatangriffsfläche unter dem Aspekt umfaßt, daß diese hinsichtlich der örtlichen Zuordnung mit der Halteranlagefläche in gleicher Weise übereinstimmt, wie der individuelle Abschnitt der Außenfläche mit dem berechneten Fixierpunkt am Zahn übereinstimmt.

16. Verfahren nach Anspruch 14 oder 15, bei dem zum Apparat eine Anzahl von Brackets gehört, wobei je eines zum Befestigen an je einem Fixierpunkt an einem Zahn bestimmt ist und jedes Bracket einen Schlitz zur Aufnahme des Bogendrahts aufweist; der Schritt Konstruktion der Apparatkonfiguration Bracketformdaten, so auch eine digitale Darstellung der Position und Neigung des Schlitzes im Bracket, einschließt; und der Schritt Berechnen der Haltergeometrie den Schritt Festlegen der Apparatangriffsfläche umfaßt, so daß ein Teil des Apparats einbezogen ist, der fluchtend auf den Schlitz des Brackets ausgerichtet wird, wenn der Apparat in das Bracket eingesetzt wird.

17. Verfahren nach Anspruch 16, bei dem der Schritt Konstruktion des Apparats den Schritt Berechnen der Bracketauslegung für die Aufnahme eines bogenförmig gestalteten Bogendrahts umfaßt.

18. Verfahren nach Anspruch 16 oder 17, bei dem der Schritt Konstruktion des Apparats den Schrift Auswählen eines

optimalen Rohlings für die Fertigung des Brackets entsprechend der digitalen Schlitzdarstellung unter einer Anzahl von Bracketrohlingen umfaßt.

19. Verfahren nach einem der vorstehenden Ansprüche, bei dem der Schritt Vermessen den Schritt Vermessen der Formen der einzelnen oberen und unteren Zähne und der Unterkieferform des Patienten und darauf aufbauend Gewinnen digitalisierter Daten zu den Formen der oberen und unteren Zähne sowie zur Unterkieferform umfaßt, wobei die Zahnformdaten auch Daten der Schneidkanten der unteren vorderen Schneidezähne und der bukkalen Höcker der unteren hinteren Zähne sowie des zentralen Kamm- oder des Randleistenbereichs der oberen hinteren Zähne beinhalten; der Schritt Ableiten der Zahnendposition die Schritte Ableiten einer Konfiguration des mit Zähnen bestückten Unterkiefers unter Berücksichtigung der Anordnung der unteren Zähne entlang der unteren Bogenkonfiguration mit miteinander kontaktierenden benachbarten Zähnen, und der unteren Bogen-konfiguration; senkrechtes Ausrichten eines jeden unteren Zahns unter dem Aspekt, daß die Schneidkanten der unteren Vorderzähne und die bukkalen Höcker der unteren hinteren Zähne im wesentlichen die gleiche Okklusionsebene einnehmen und einen angestrebten Neigungswinkel aufweisen; Anpassen der mit Zähnen bestückten unteren Bogenkonfiguration zur Erzielung einer Endkonfiguration des mit Zähnen bestückten Unterkiefers durch labial-linguale Positionierung der unteren Zähne, um deren Schneidkanten und bukkalen Höcker auf einen glatten Bogen in der Okklusionsebene auszurichten, wobei benachbarte Zähne miteinander kontaktieren; und Ableiten einer Endkonfiguration des mit Zähnen bestückten Oberkiefers umfaßt, bei der die zentralen Höckerfurchen bzw. die Randleisten der hinteren Zähne horizontal mit der Endkonfiguration des mit Zähnen bestückten Unterkiefers und vertikal mit der Okklusionsebene übereinstimmen; die Vorderzähne mit ihren Schneidkanten unterhalb der Okklusionsebene angeordnet sind, so daß sie eine festgelegte Überdeckung und ein horizontales Offset in labialer Richtung gegenüber der Endkonfiguration des mit Zähnen bestückten Unterkiefers erhalten, damit ein bestimmter Abstand zwischen den lingualen Seiten der unteren Vorderzähne und den labialen Seiten der unteren Vorderzähne hergestellt wird; der Schritt Konstruktion des Apparats den Schritt Berechnen einer Bracketkonfiguration für die Brackets der einzelnen oberen und unteren Zähne einschließlich des Schlitzwinkels und der Schlitztiefe jedes Brackets und Berechnen der Bogendrahtform für den oberen und unteren Bogendraht, und zwar auf der Grundlage der berechneten Zahnendpositionen, der festgelegten Ebenen für den oberen und unteren Bogendraht, der Zahnformen und der Fixierpositionen; und der Schritt Fertigen des Apparats die Schritte Fertigen des oberen und unteren Bogendrahts in Übereinstimmung mit den berechneten Bogendrahtformen und Fertigen der Brackets entsprechend den berechneten Bracketkonfigurationen umfaßt.

20. Verfahren nach einem der vorstehenden Ansprüche, zu dem ferner die Schritte Bereitstellen von Kriterien für die Beschreibung der Abstände zwischen den einzelnen Zähnen und der Drehachse des Unterkiefers gehören, und bei dem der Schritt Ableiten der Zahnendstellung die Schritte Berechnen einer Molarenanhebungskomponente aus den Kriterien und den Zahnformdaten; und vertikales Ausrichten der oberen und unteren Molaren umfaßt, so daß ihre Höcker entsprechend unterhalb oder oberhalb in einem Abstand zur Okklusionsebene angeordnet werden, der mit der berechneten Molarenanhebung in einer bestimmten Beziehung steht.

21. Verfahren nach Anspruch 20, wenn dieser von Anspruch 19 abhängig ist, bei dem der Schritt Ableiten der Endkonfiguration des mit Zähnen bestückten Oberkiefers das Ableiten der Konfiguration umfaßt, bei der die Schneidkanten der oberen Vorderzähne so weit unterhalb der Okklusionsebene angeordnet sind, daß festgelegte Überdeckungen erreicht werden, die in einer bestimmten Beziehung zur berechneten Molarenanhebung stehen.

22. Verfahren nach Anspruch 20 oder 21, bei dem der Schritt Berechnen der Molarenanhebungskomponente die Schritte Bestimmen der Okklusionspaare der entsprechenden oberen und unteren hinteren Zähne des Patienten und Bestimmen eines senkrechten Abstands zwischen dem höchsten Punkt des unteren Zahns des Paars und dem tiefsten Punkt des oberen Zahns des Paars für ein jedes Paar aus den digitalisierten Zahnformdaten, wenn sich die Kiefer in geschlossener Stellung befinden; Ausgleichen eines jeden ermittelten vertikalen Abstands mittels eines Faktors, der einem Abstand eines jeden Paares zur Drehachse proportional ist, und Auswählen des größten ausgeglichenen vertikalen Abstands, indem aus den digitalisierten Daten die Endpositionen der Unterkieferzähne des Patienten berechnet werden, bei denen sich die höchsten Punkte dieser Zähne hinsichtlich der vertikalen Position an einer weitestgehend flachen Okklusionsfläche befinden; und Berechnen der Endpositionen der sich entsprechend bis unter und über die Okklusionsfläche erstreckenden oberen und unteren Molaren des Patienten umfaßt.

23. Verfahren nach einem der vorstehenden Ansprüche, zu dem des weiteren die Schritte Bereitstellen eines Systems für die Konstruktion und zum Fertigen kieferorthopädischer Apparate einschließlich eines Dateneingabe-Untersystems zur Digitalisierung der Eingabedaten von gemessenen anatomischen Formen und zur Erzeugung von Ein-

gangssignalen als Träger der digitalisierten Eingabedaten, eines Datenverarbeitungs-Untersystems zur Verarbeitung der digitalisierten Eingangssignale und zur Erzeugung entsprechender Ausgangssignale als Träger der Steuersignale und eines Apparatfertigungs-Ausrüstungsuntersystems mit der dazugehörigen Fertigungsanlage zur durch die Ausgangssignale gesteuerten Herstellung eines individuellen kieferorthopädischen Apparats für die Behandlung des Patienten durch Bewegen der Zähne des Patienten in die bevorzugten Endpositionen; und Erzeugen von Ausgangssignalen für die Steuerung des Apparatfertigungs-Ausrüstungsuntersystems mit Hilfe des Datenverarbeitungs-Untersystems aus der abgeleiteten Bogenform zur Herstellung eines individuellen kieferorthopädischen Apparats; sowie Fertigen des individuellen kieferorthopädischen Apparats mit der individuellen Konfiguration mit Hilfe des Apparatfertigungs-Ausrüstungsuntersystems entsprechend dem Ausgangssignal und den Steuersignalen gehören.

24. Verfahren nach Anspruch 23, bei dem zum individuellen kieferorthopädischen Apparat ein Bogendraht in gebogener Form, die mathematisch in Beziehung steht zur Skelettbogenform der Mandibularalveolenmulde; zum Apparatfertigungs-Ausrüstungsuntersystem eine Drahtbiegevorrichtung, die durch Signale gesteuert wird, für die das Ausgangssignal als Träger dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Drahtbiegevorrichtung gehören, so daß sie mit einem Draht gespeist wird und das Biegen des zugeführten Drahts entsprechend der individuellen Bogendrahtkonfiguration erfolgt, um den Bogendraht an den Zähnen eines Kiefers an den entsprechenden Fixierpunkten fixieren zu können.

25. Verfahren nach Anspruch 24, bei dem die digitalisierten Eingabedaten Informationen enthalten, aus denen der Fixierpunkt des Apparats und die Neigung der Fläche am Fixierpunkt abgeleitet werden können; bei dem zum individuellen kierferorthopädischen Apparat eine Anzahl von Brackets, und zwar je Fixierpunkt des Zahns eines, gehört, wobei jedes eine Basis, die sich am entsprechenden Fixierpunkt fixieren läßt, und einen für die Aufnahme des Bogendrahts bestimmten Bogendrahtschlitz aufweist; zum Apparatfertigungs-Ausrüstungsuntersystem eine Bracketfertigungsvorrichtung gehört, die mittels Steuersignale gesteuert wird, für die das Ausgangssignal als Träger dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Bracketfertigungsvorrichtung gehört, die dazu dienen, jedes Bracket mit dem Bogendrahtschlitz in einer solchen Richtung zur Basis ausgerichtet zu fertigen, daß dieser einen Punkt am Bogendraht bezüglich des Fixierpunktes des entsprechenden Zahns stützt und orientiert und so eine Kraft zwischen diesen Punkten überträgt und schließlich den Zahn in Richtung seiner Endposition drückt.

26. Verfahren nach Anspruch 25, bei dem die digitalisierten Eingabedaten Informationen zum Zahnumriß enthalten; zum individuellen kieferorthopädischen Apparat ein Bracketeinsetzhalter für jedes Bracket mit einer Fläche zur individuell paßgerechten Positionierung des Halters an der Zahnfläche und zur Positionierung des Brackets am Zahn an dessen Fixierpunkt gehört; zum Apparatfertigungs-Ausrüstungsuntersystem eine Bracketeinsetzhalter-Fertigungsvorrichtung gehört, die mit Hilfe der Steuersignale gesteuert wird, für die als Träger das Ausgangssignal dient; und zum Ausgangssignal eine Reihe von Steuersignalen zur Steuerung der Vorrichtung für die Fertigung von Bracketeinsetzhaltern gehört.

27. Verfahren nach Anspruch 25 oder 26, bei dem der Schritt Apparatfertigung die Schritte Bereitstellen einer Anzahl von Bracketrohlingen; und Herstellen eines Brackets aus dem Bracketrohling durch Ausbilden eines Bogendrahtschlitzes in jedem der Bracketrohlinge in einer solchen Weise umfaßt, daß jeder Schlitz beim Befestigen des Brakkets am Fixierpunkt eines Zahns in einer Bogendrahtebene angeordnet ist, wobei sich der Zahn in seiner abgeleiteten Endposition befindet.

28. Verfahren nach Anspruch 27, bei dem der Schritt Ableiten der Bogenform den Schritt aus den digitalisierten Daten vorgenommenes Ableiten einer Skelettbogenform umfaßt, die mathematisch die Form der Kompakta des Patienten mittels einer glatten stetigen Gleichung darstellt, die ihrerseits von den digitalisierten Grenzpunkten abgeleitet wurde, die den Grenzen der Kompakta des Patienten entsprechen und die Bogenformgleichung mit Hilfe einer Reihe von einander berührenden Kreissegmenten darstellen; der Schritt Bracketschlitzfräsen den Schritt Ausführen des Schlitzes bis auf eine Tiefe, die durch das Sichschneiden der Bogenformgleichung mit dem Bracket bestimmt wird, wenn das Bracket am Fixierpunkt eines in seiner abgeleiteten Endposition befindlichen Zahns befestigt ist; und der Schritt Bracketschlitzfräsen den Schritt Ausführen des Schlitzes bis zu einer Schlitzgrundflächenkurve mit dem Radius des schneidenden Kreissegments der Bogenformgleichung umfaßt.

29. Verfahren nach einem der vorstehenden Ansprüche, bei dem zur Gewährleistung eines optimalen Zwischenraums zwischen dem Apparat und der Gingiva eines Patienten sowie eines optimalen Zwischenraums zu den Zähnen des anderen Kiefers des Patienten der Schritt Festlegen der Position des Fixierpunktes die Schritte Digitalisieren der

Geometrie von Teilen des Apparats; anhand der digitalisierten Zahnformdaten erfolgendes Berechnen der Beziehungen zwischen Punkten auf den Zahnflächen der gegenüberliegenden Kiefer des Patienten; anhand der digitalisierten Daten erfolgendes Berechnen der Stellen an den Oberflächen der Zähne eines Kiefers des Patienten, an denen der Apparat zu fixieren ist, damit ein optimaler Zwischenraum zwischen dem Apparat und der Gingiva eines Patienten und ein optimaler Zwischenraum zu den Zähnen des anderen Kiefers des Patienten gewährleistet wird; sowie Konstruktion der Apparatkonfiguration entsprechend den berechneten Orten für die Fixierung des Apparats an den Zähnen des Patienten umfaßt.

30. Verfahren nach einem der Ansprüche 1 bis 23, bei dem zu dem individuellen kieferorthopädischen Apparat ein Bogendraht gehört; der Schritt Konstruktion des Apparats den Schritt Ableiten der digitalen Bogendrahtformdaten, die zumindest teilweise auf der abgeleiteten Bogenform basieren; und der Schritt Erzeugen des Steuersignals den Schritt anhand der digitalen Bogendrahtformdaten erfolgendenes Erzeugen eines Drahtform-Steuersignals, so daß von der Bogendrahtformvorrichtung, wenn dies an die Vorrichtung angelegt wird, ein individueller kieferorthopädischer Apparat entsprechend den anatomischen Formgegebenheiten des Mundes des Patienten hergestellt wird; und Formen einer Länge des kieferorthopädischen Bogendrahtmaterials in eine angestrebte Form entsprechend dem Drahtform-Steuersignal zwecks Herstellung eines individuellen Bogendrahts umfaßt.

31. Verfahren nach Anspruch 30, bei dem der Schritt Erzeugen eines Steuersignals die Schritte Bereitstellen von Materialeigenschaftsdaten des Bogendrahts; und Erzeugen des Drahtbiegesteuersignals anhand der Materialeigenschaftsdaten des Bogendrahts umfaßt.

32. Verfahren nach Anspruch 30 oder 31, das ferner die Schritte Messen der Bogendrahtspannweite zwischen zwei Punkten an dem hergestellten individuellen Bogendraht; Berechnen einer Konstruktions-Bogendrahtspannweite aus den abgeleiteten Bogendrahtformdaten; Vergleichen der gemessenen Bogendrahtspannweite mit der Konstruktions-Bogendrahtspannweite und Übermitteln eines Ergebnisses des Vergleichs; sowie Erzeugen des Drahtbiege-Steuersignals entsprechend dem übermittelten Vergleichsergebnis umfaßt.

33. Fertigungskomplex für die Herstellung eines individuellen kieferorthopädischen Apparats, zu dessen Bestandteilen zählen: technische Mittel (30, 30a, 33, 43, 50, 57) zum Vermessen der anatomischen Formen (20 bis 24) des Mundes (18) des Patienten (12) und darauf aufbauend zur Erzeugung digitalisierter Daten zur anatomischen Form (26) einschließlich dreidimensionaler Zahnformdaten, die die Formen der einzelnen Zähne des Patienten darstellen, und ein digitaler Computer (30b, 30c) einschließlich der Programme zur Ableitung einer idealen Zahnbogenform aus den digitalisierten Daten (26) mit Hilfe eines speziell programmierten Computers (30b) zur Gewinnung eines digitalisierten Bogenformmodells, das zumindest teilweise von den digitalisierten Daten zur anatomischen Form abhängt; zum Ableiten der Zahnendpostionen aus den digitalisierten anatomischen Daten (26) und der abgeleiteten digitalisierten idealen Bogenform mit Hilfe des Computers zur mesiodistalen Anordnung der Zähne auf der abgeleiteten idealen Zahnbogenform und zur Bewegung der Zähne in bezug auf den abgeleiteten idealen Zahnbogen in Positionen und in Stellungen, die zumindest teilweise auf den dreidimensionalen Zahnformdaten für die jeweiligen Zähne basieren; zum Vorgeben eines Apparatfixierpunktes an jedem Zahn einer Anzahl von Zähnen; zur Konstruktion einer Apparatkonfiguration anhand der digitalisierten Zahnformdaten, der vorgegebenen Apparatfixierpunkten und der abgeleiteten Zahnendpositionen unter dem Aspekt, daß der entsprechend diesen Daten gefertigte individuelle Apparat eine solche Auslegung erhält, daß eine Verbindung zwischen den Zähnen an ihrem jeweiligen Fixierpunkt und den Zähnen in den abgeleiteten Zahnendpositionen besteht; zum Erzeugen eines Maschinencodes (42), der mit der konstruierten Apparatkonfiguration in einer bestimmten Beziehung stehende geometrische Informationen enthält; und eine Fertigungsanlage (38, 39, 40, 41) zum automatischen Fertigen eines individuellen kieferorthopädischen Apparats (25) durch Formen des Apparats (25) entsprechend dem Maschinenkode (42) in Übereinstimmung mit den geometrischen Informationen, so daß auf diese Weise der Apparat (25) mit der konstruierten Konfiguration entsteht.

34. Fertigungskomplex nach Anspruch 33, bei dem zur Fertigungsanlage (38) eine Bogendrahtformvorrichtung (40) mit technischen Mitteln (66 bis 71) zum Formen einer Länge von kieferorthopädischem Bogendrahtmaterial (69) in eine angestrebte Form entsprechend einem an diese technischen Mittel angelegten Drahtform-Steuersignal; sowie Programmeinheiten mit Einheiten zur Erzeugung eines Drahtform-Steuersignals in Übereinstimmung mit den digitalen Bogendrahtformdaten gehören, so daß bei Anliegen des Signals an der Bogendrahtformvorrichtung diese einen individuellen kieferorthopädischen Bogendraht (64) entsprechend der jeweiligen anatomischen Form des Mundes (18) des Patienten herstellt.

35. Fertigungskomplex nach Anspruch 34, bei dem die abgeleiteten digitalen Bogendrahtformdaten die mit einer Län-

genkomponente der abgeleiteten digitalen Bogendrahtformdaten in einer Beziehung stehenden Drahtlängendaten und die mit einer Krümmungskomponente der abgeleiteten digitalen Bogendrahtformdaten in einer Beziehung stehenden Drahtkrümmungsdaten enthalten, die eine Funktion der Längenkomponente sind; bei dem zum Drahtform-Steuersignal ein als Träger der Drahtlängendaten dienendes Drahtzuführungssteuersignal und ein als Träger der Drahtkrümmungsdaten dienendes Drahtbiegesteuersignal gehören; bei dem zu den Programmeinheiten Einheiten zur Erzeugung des Drahtzuführungssteuersignals und Einheiten zur Erzeugung eines Drahtbiegesteuersignals und zur Übertragung der Steuersignale an die Bogendrahtformvorrichtung gehören; und bei dem zur Bogendrahtformvorrichtung (40) eine Zuführungsvorrichtung (68) zur Zuführung des kieferorthopädischen Bogendrahtmaterials (69) in Längsrichtung entsprechend dem Drahtzuführungssteuersignal und eine Vorrichtung (70) zum Biegen des mit Hilfe der Drahtzuführungsvorrichtung (68) zugeführten Bogendrahtmaterials (69) in Querrichtung entsprechend dem Drahtbiegesteuersignal und synchron mit der Zuführung des Bogendrahtmaterials (69) gehören.

36. Fertigungskomplex nach Anspruch 34, bei dem die digitalen Bogendrahtformdaten eine digitale Darstellung einer Reihe von zusammenhängenden Drahtsegmenten sind, von denen ein jedes eine Längenkomponente und eine Krümmungskomponente aufweist; und zur Bogendrahtformvorrichtung eine Vorrichtung zur Zuführung einer Reihe von Längen des kieferorthopädischen Bogendrahtmaterials in Längsrichtung entsprechend den jeweiligen Drahtlängenkomponenten in Übereinstimmung mit den Drahtlängendaten und eine Vorrichtung (70) zum Biegen einer jeden zugeführten Länge des Bogendrahtmaterials (69) in eine Form mit einer Krümmung entsprechend der jeweiligen Drahtkrümmungskomponente in Übereinstimmung mit den Drahtkrümmungsdaten gehören.

37. Fertigungskomplex nach Anspruch 36, bei dem jedes Drahtsegment die Form eines Kreissegments mit einer Segmentlängenkomponente als Ausdruck für eine tangentiale Länge des Bogendrahtmaterials und mit einer Segmentkrümmungskomponente als Ausdruck eines konstanten Krümmungsradius des Materials über die tangentiale Länge des Segments aufweist; und zur Zuführungsvorrichtung (68) eine Vorrichtung für die Zuführung einer Reihe von tangentialen Längen des kieferorthopädischen Bogendrahtmaterials (69) und zur Biegevorrichtung (70) eine Vorrichtung zum Biegen einer jeden zugeführten Länge des Bogendrahtsegments in einer Form mit gleichbleibendem Radius entsprechend den Drahtkrümmungsdaten gehören.

38. Fertigungskomplex nach Anspruch 37, bei dem die Zuführungsvorrichtung (68) für die fortlaufende Zuführung einer Reihe von Längen des Bogendrahtmaterials, die den Längenkomponenten der Kreissegmente gleich sind, entsprechend dem Drahtzuführungssignal auf einer längs ausgerichteten Bahn vorgesehen ist; bei dem zur Biegevorrichtung (70) ein Biegeelement (70b), das entsprechend dem Drahtbiegesignal quer zur Bahn bewegt werden kann, um so die Biegung in Querrichtung auf das Segment zu übertragen, und ein Querrichtungspositionssensor zur Erzeugung eines auf die Biegung ansprechenden Rückkopplungssignals gehören; und bei dem zum Computer (30b, 30c) eine Einheit zur Modifizierung des Drahtbiegesteuersignals entsprechend dem Rückkopplungssignal zur Gewährleistung der geschlossenen Steuerung des Biegeelements gehört.

39. Fertigungskomplex nach einem der Ansprüche 36 bis 38, zu dem des weiteren eine Vorrichtung zum Messen der Bogendrahtspannweite zwischen Punkten am ersten und letzten Segment der Reihe von hergestellten individuellen kieferorthopädischen Bogendrähten (64) gehört; bei dem zu den Programmeinheiten Einheiten zur Berechnung einer Bogendraht-Konstruktionsspannweite anhand der abgeleiteten Bogendrahtformdaten; sowie Einheiten zum Vergleich der gemessenen Bogendrahtspannweite mit der Bogendraht-Konstruktionsspannweite und zum Speichern der Vergleichsergebnisse gehören; und bei dem die Programmeinheiten für die Erzeugung des Drahtformsteuersignals entsprechend einem gespeicherten Vergleichsergebnis vorgesehen sind.

40. Fertigungskomplex nach einem der Ansprüche 36 bis 39, bei dem zu den Programmeinheiten mit den Einheiten zur Erzeugung der Drahtformsteuersignale im Datenaustausch stehende Einheiten für den Empfang der Materialeigenschaftsdaten des Bogendrahtmaterials und für die Modifizierung des Drahtbiegesteuersignals entsprechend den Eigenschaftsdaten gehören, wodurch ein Ausgleich der elastischen Eigenschaften des Materials ermöglicht wird.

41. Fertigungskomplex nach einem der Ansprüche 33 bis 40, bei dem zur Fertigungsanlage (38) eine Bracketfertigungsvorrichtung (39) mit einer Spannvorrichtung (73) einschließlich dazugehörender Elemente zur Aufnahme eines Bracketrohlings (80) für die Herstellung; und Elemente (75 bis 77) zur Bearbeitung mindestens einer Oberfläche eines in der Spannvorrichtung (73) eingespannten Bracketrohlings (80) entsprechend einem Fertigungsanlagensteuersignal, das in Übereinstimmung mit dem Steuersignal an diese angelegt wurde, einschließlich einem Element (77) zur Bearbeitung des in der Spannvorrichtung (73) eingespannten Bracketrohlings (80) zur Fertigung eines Brackets, das mit einem Schlitz mit einer berechneten geometrischen Beziehung zur Befestigungsfläche der

Bracketbasis ausgeführt wird, gehören.

42. Fertigungskomplex nach Anspruch 41, bei dem jeder Schlitz durch eine im allgemeinen parallele Ober- und Unterseite, die eine Schlitzneigung definieren, und eine Schlitzgrundfläche an einem seiner Enden in größter Nähe zur Bracketbasis, die eine Schlitzposition definiert, gekennzeichnet ist; und jede berechnete geometrische Beziehung eines Schlitzes zur Befestigungsfläche eines Brackets durch die Schlitzneigung und eine Schlitzanordnung in bezug auf die Befestigungsfläche gekennzeichnet ist; bei dem das erzeugte Fertigungsanlagensteuersignal als Träger der Fertigungsanlageristeuerbefehle zur Betätigung der Fertigungselemente (75 bis 77) für die Bearbeitung des Bracketrohlings (80) zwecks Herstellung eines Brackets mit einem Schlitz (80b) mit der berechneten Schlitzneigung und -anordnung bezüglich der Befestigungsfläche dient; bei dem der Schlitz (80b) jedes Brackets so ausgeführt ist, daß ein Bogendraht (64) mit einer individuellen Krümmung unmittelbar am Zahn, an dem das Bracket befestigt werden soll, aufgenommen wird; bei dem jede berechnete geometrische Beziehung eines Schlitzes zur Befestigungsfläche eines Brackets durch eine mit der individuellen Krümmung des unmittelbar daran anliegenden Bogendrahts (64) übereinstimmende Schlitzgrundflächenkrümmung gekennzeichnet ist; und das erzeugte Fertigungsanlagensteuersignal als Träger von Fertigungsanlagensteuerbefehlen zur Betätigung der Fertigungselemente für die Bearbeitung des Bracketrohlings zwecks Herstellung eines mit einem Schlitz mit der berechneten Schlitzgrundflächenkrümmung ausgeführten Brackets dient.

43. Fertigungskomplex nach Anspruch 41 oder 42, bei dem zu den Fertigungselementen (75 bis 77) Elemente (77) zum Fräsen eines Schlitzes (80b) entsprechend dem Steuersignal gehören.

44. Fertigungskomplex nach einem der Ansprüche 41 bis 43, bei dem die Spannvorrichtung (73) und die Fertigungselemente (75 bis 77) an einem Ständer (72) montiert sind; und zu dem technische Mittel (74) zum Ausrichten der Spannvorrichtung (73) auf einen bestimmten Winkel bezüglich des Ständers (72) und der Fertigungselemenete (75 bis 77) sowie technische Mittel (75, 76) zum Bewegen der Fertigungselemente (77) relativ zum Ständer (72) und zur Spannvorrichtung (73) entsprechend dem Steuersignal gehören.

45. Fertigungskomplex nach einem der Ansprüche 33 bis 44, bei dem zur Fertigungsanlage (38) eine Halterfertigungsvorrichtung einschließlich der technischen Mittel (81) zur Fertigung eines Halters für das Einsetzen eines individuellen kieferorthopädischen Apparats am Zahn eines Patienten, einschließlich der dazugehörenden technischen Mittel (81) zum Bearbeiten der Konturen einer Fläche eines Halterrohlingsmaterials (83) entsprechend einem dieser Vorrichtung zugeführten Steuersignal gehört; zu den technischen Mitteln zur Vermessung (30, 30a, 33, 43, 50, 57) Einheiten zur Bereitstellung einer digitalisierten Aufzeichnung der Zahnformen eines Patienten (12) und der mit dieser Zahnformaufzeichnung verknüpften Stellen der Apparatfixierpunkte auf den Zahnoberflächen gehören; zu den Programmeinheiten Einheiten zur anhand der Aufzeichnung der digitalisierten Zahnformen und der Fixierpunkte erfolgenden Berechnung der Haltergeometrie, die eine Halteranlagefläche definiert, die einem individuellen Abschnitt der Kronenaußenfläche eines Zahns entspricht, und eine Apparatangriffsfläche definiert, die die gleiche örtliche Zuordnung gegenüber der Halteranlagefläche hat wie der individuelle Abschnitt der Außenfläche gegenüber dem Fixierpunkt am Zahn, gehören; und zu den Einheiten für die Erzeugung von Signalen Einheiten für die Erzeugung eines Fertigungsanlagensteuersignals als Träger der Fertigungsanlagensteuerbefehle für die Fertigung eines Halters (82) entsprechend der berechneten Haltergeometrie gehören.

46. Fertigungskomplex nach Anspruch 45, bei dem zum Apparat eine Anzahl von Brackets (80), und zwar je eines zum Fixieren an jedem Fixierpunkt an einem Zahn gehören; und zu dem des weiteren Einheiten zur Bereitstellung digitalisierter Bracketformdaten einer Außenfläche eines jeden an einem Fixierpunkt zu befestigenden Brackets gehören; und bei dem zur Haltergeometrieberechnungseinheit eine Einheit zur Festlegung der Halteranlagefläche am Apparat gehört, damit, auch gemäß den digitalisierten Bracketformdaten, eine Übereinstimmung mit der vorgegebenen Apparatgeometrie gewährleistet wird.

## Revendications

1. Procédé de fabrication sur mesure d'un appareil orthodontique pour replacer les dents d'un patient dans une position finale choisie, ce procédé comprenant les étapes consistant à mesurer l'anatomie de la bouche du patient et produire à partir de ces mesures, des données numérisées de ladite anatomie comprenant des données numérisées représentant en trois dimensions la forme de chacune de ses dents ; définir une arcade dentaire idéale en traitant les données numérisées de celle anatomie avec un ordinateur numérique programmé pour produire un modèle mathématique d'arcade dentaire dépendant au moins en partie des données numérisées de l'anatomie ; définir avec l'ordinateur les positions finales des dents à partir des données numérisées de l'anatomie et du modèle

mathématique numérisé d'arcade dentaire pour espacer dans le sens mesio-distal les dents le long de l'arcade dentaire idéale choisie et placer les dents par rapport à celle arcade dentaire idéale en positions et orientations reposant au moins en partie sur les données des formes des dents en trois dimensions pour chacune des dents respectives prises individuellement; concevoir sur mesure avec l'ordinateur un appareil orthodontique à partir des données numérisées des formes de dents en trois dimensions, des points de connexion de l'appareil établi et de la position finale choisie des dents, de telle sorte que cet appareil orthodontique sur mesure possède une configuration dont les dimensions sont établies de manière à faire coïncider les dents et leurs points de connexion respectifs, les dents étant dans leur positions finales choisies ; générer des signaux de commande assimilables par une machine contenant des informations géométriques corrélées avec les résultats de l'étape de conception de l'appareil ; et fabriquer sur mesure de manière automatisée un appareil orthodontique avec une machine sensible aux signaux de commande assimilables par celle machine pour façonner cet appareil selon les informations géométriques contenues dans les signaux de commande afin de former un appareil orthodontique sur mesure ayant la configuration dessinée.

2. Procédé selon la revendication 1, dans lequel les dents comprennent les dents mandibulaires et les dents maxillaires et dans lequel la mesure de leur anatomie comprend les étapes consistant à mesurer la mâchoire inférieure d'un patient et produire ainsi des données numérisées de la forme de cette mâchoire et à mesurer ses dents mandibulaires et maxillaires et produire ainsi des données numérisées de la forme de chaque dent; l'extraction de l'arcade comprend l'étape consistant à extraire avec l'ordinateur l'arcade squelettique d'un mandibule à partir des données numérisées de la forme de la mâchoire inférieure ; et l'extraction de la position finale des dents comprend l'étape consistant à extraire ces positions des données de leur forme et de celle de l'arcade squelettique du mandibule extraite pour y disposer les dents.

3. Procédé selon la revendication 2, dans lequel chaque dent a une couronne, une racine et un axe longitudinal généralement vertical passant par le centre de la couronne, faisant intersection avec un point central de la gencive où la couronne rencontre la racine et dans lequel la mesure de la mâchoire inférieure comprend l'étape consistant à numériser les points de mesure définissant un sillon mandibulaire dans lequel les racines des dents mandibulaires doivent se loger ; l'extraction de l'arcade squelettique du mandibule comprend l'étape consistant à faire correspondre la courbe lissée continue de l'équation du sillon mandibulaire aux points de mesure numérisés de ce sillon mandibulaire et à produire une représentation numérisée de l'équation de cette courbe; l'extraction de la position finale des dents comprend l'étape consistant à extraire les positions centrant chaque dent mandibulaire en plaçant leur axe longitudinal approximativement sur la courbe de l'équation du sillon mandibulaire à proximité du point central de la gencive de la dent et plaçant les pointes des dents mandibulaires sur une courbe lissée continue extraite par ajustement de l'équation du sillon mandibulaire ; et la conception de l'appareil comprend l'étape consistant à définir la configuration de cet appareil par une série de valeurs numériques extraites de la courbe lissée continue.

4. Procédé selon l'une quelconque des revendications précédentes, dans lequel la mesure comprend l'étape consistant à numériser des données de la forme de la mâchoire inférieure du patient en numérisant les points correspondant aux contours de son os cortical et l'étape d'extraction de l'arcade consistant à extraire à partir des données numérisées une arcade squelettique représentant mathématiquement la forme de l'os cortical du patient par la courbe d'équation lissée continue tirée des points de contour numérisés.

5. Procédé selon la revendication 4, dans lequel l'équation lissée continue est une équation de la fonction spline cubique des points se rapportant aux points de contour numérisés.

6. Procédé selon l'une quelconque des revendications précédentes dans lequel l'extraction de l'arcade comprend l'étape consistant à définir une courbe basée sur les données numérisées de la forme anatomique et lisser cette courbe par la méthode statistique de l'ajustement optimal pour générer une équation lissée continue de cette arcade, l'étape d'extraction de la position finale et celle de conception de la configuration de l'appareil étant basées au moins en partie sur cette équation de l'arcade.

7. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre les étapes consistant à représenter numériquement, dans l'ordinateur, l'arcade extraite par une équation représenter cette équation de l'arcade par une série d'arcs de cercle tangentiels successifs ; dans lequel la conception de l'appareil comprend l'étape consistant à concevoir un appareil au moins en partie arqué sur la base d'une série de valeurs numériques représentant des longueurs d'arcs de cercle et des rayons tirés des arcs de cercle de l'équation de la forme d'arcade et, la fabrication de l'appareil comprend l'étape consistant à convertir les longueurs des arcs et des rayons en une série de commandes produisant des signaux de commande et, en réponse aux signaux, à former séquen-

tiellement l'appareil selon un rayon correspondant à chaque longueur d'arc en réponse aux signaux pour se conformer à la configuration conçue dudit appareil.

8. Procédé selon l'une quelconque des revendications précédentes dans lequel la mesure comprend l'étape consistant à numériser les distances entre le point de contact mésial et le point de contact distal de chaque dent pour définir la largeur mésio-distale de chacune ; l'extraction des positions finales des dents comprend l'étape consistant à extraire les positions finales des dents pour mettre au contact l'un de l'autre les points de contact mésial et distal voisins de deux dents adjacentes pour former un arc de placement des dents dont la forme épouse celle de l'arcade extraite et approximativement en longueur égale à la somme des largeurs mésio-distales des dents placées sur cette arcade ; et la conception de l'appareil comprend l'étape consistant à concevoir la configuration de l'appareil en partie à partir des largeurs mésio-distales et de l'arcade de placement des dents.

9. Procédé selon l'une quelconque des revendications précédentes, dans lequel la mesure comprend l'étape consistant à numériser, pour chaque dent, des données relatives au profil de celle dent sous forme d'une série de points de données numérisées représentant la configuration de la surface de la dent au moins le long d'un de ces profils généralement vertical et cohérent avec la morphologie lèvres-langue ; l'établissement du point de connexion comprend l'étape consistant à situer un point de connexion de l'appareil à la surface de chacune des dents le long du profil de celles-ci ; et la conception de l'appareil comprend l'étape consistant à concevoir, à partir des séries de point de données numérisées représentant la configuration de la surface des dents, les points de connexion établis et les positions des dents extraites.

10. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'extraction de l'arcade comprend les étapes consistant à comparer les points controlatéraux correspondants sur les côtés opposés de l'arcade et, sur la base de cette comparaison, calculer une arcade modifiée présentant sur ces côtés une symétrie par rapport à son centre ; et concevoir l'appareil sur la base au moins en partie de l'arcade modifiée.

11. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'étape de mesure comprend l'étape consistant à numériser les données des points des surfaces labiales et linguales de chacune des dents du patient, ce procédé comprenant en outre l'extraction à partir de ces données numérisées d'une représentation numérique de l'orientation de l'axe longitudinal de la couronne de chaque dent par rapport aux points et le calcul, à partir des données numérisées, des positions finales des dents et des représentations numériques des axes longitudinaux des couronnes des dents, les positions finales calculées incluant les orientations préférées des axes longitudinaux des couronnes.

12. Procédé selon la revendication 11, comprenant en outre les étapes consistant à calculer les orientations préférées des axes longitudinaux des couronnes pour une pluralité de patients et à produire un enregistrement de ces orientations préférées calculées ; enregistrer les données personnelles de chacun des patients, corréler les données personnelles avec les orientations préférées calculées des axes longitudinaux des couronnes et placer les patients en groupe de population selon la corrélation ; et produire un enregistrement statistique des orientations préférées des axes longitudinaux des couronnes pour les patients des groupes de population.

13. Procédé selon l'une quelconque des revendications précédentes, dans lequel la conception de l'appareil comprend l'étape consistant à concevoir, à partir des données de la forme des dents, des configurations de gabarit pour la mise en place de l'appareil, chaque configuration ayant une surface de gabarit épousant la surface d'une dent respective pour faciliter la mise en place du point de connexion avec celle-ci et la connexion effective de l'appareil à celle-ci ; la production d'un signal de commande comprend l'étape consistant à produire les signaux de commande au moins en partie selon les configurations de gabarit de mise en place de l'appareil ; et la fabrication de l'appareil comprend l'étape de fabrication automatique avec la machine des gabarits de mise en place de l'appareil en réponse aux signaux de commande pour correspondre aux configurations conçues des gabarit de mise en place.

14. Procédé selon la revendication 13, dans lequel la conception des configurations des gabarits de mise en place de l'appareil comprend les étapes consistant à calculer, à partir des données numérisées des formes des dents et des points de connexion définis, la géométrie des gabarits présentant une surface de mise en place du gabarit épousant la partie unique de la surface externe de la couronne d'une dent et définir une surface engageant l'appareil ayant vis à vis de la surface de mise en place du gabarit le même emplacement que la partie unique de la surface externe vis à vis du point de connexion avec la dent, de telle manière que la machine, quand elle est actionnée en réponse aux signaux de commande, façonne un gabarit qui, lorsqu'il est ajusté sur la dent, positionne et oriente un appareil avec lequel il est en prise au point de connexion.

15. Procédé selon la revendication 14, dans lequel la définition du point de connexion comprend l'étape consistant à calculer les points de connexion à partir des données numérisées de la forme des dents et le calcul de la géométrie du gabarit comprend l'étape consistant à définir la surface de prise de l'appareil de telle manière que l'emplacement vis à vis de la surface de mise en place du gabarit soit le même que celui de la partie unique de la surface externe vis à vis du point calculé de connexion sur la dent.

16. Procédé selon soit la revendication 14, soit la revendication 15, dans lequel l'appareil comprend une pluralité de crochets, un par connexion à chaque point de connexion d'une dent, chaque crochet ayant une fente recevant un arc dentaire ; la conception de la configuration de l'appareil comprend des données des formes des crochets incluant une représentation numérique de la position et de l'inclinaison de la fente dans le crochet ; et le calcul de la géométrie du gabarit comprend l'étape consistant à définir la surface de prise de l'appareil pour inclure une partie de ce dernier s'alignant sur la fente du crochet quand ce dernier est en prise avec cette surface.

17. Procédé selon la revendication 16, dans lequel la conception de l'appareil comprend l'étape consistant à calculer le dessin des crochets pour y adapter un arc dentaire de forme précise.

18. Procédé selon soit la revendication 16, soit la revendication 17, dans lequel la conception de l'appareil comprend l'étape consistant à sélectionner, à partir d'une pluralité d'ébauches de crochet, une ébauche optimale pour la fabrication du crochet selon la représentation numérique de l'encoche.

19. Procédé selon l'une quelconque des revendications précédentes, dans la mesure comprend l'étape consistant à mesurer les formes individuelles des dents supérieures et inférieures et la forme de la mâchoire inférieure du patient et à produire ainsi des données numérisées des dents supérieures et inférieures et des données de la forme de la mâchoire inférieure, les données de la forme des dents comprenant celles des pointes incisives des dents antérieures inférieures et des pointes cuspides buccales des dents postérieures inférieures et les emplacements des crêtes centrales ou marginales des dents postérieures supérieures ; l'extraction de la position finale des dents comprend les étapes consistant à extraire une configuration de la mâchoire inférieure portant des dents sur la base d'un assemblage de dents inférieures sur la configuration de l'arcade inférieure, les dents adjacentes étant au contact les unes des autres de l'arcade inférieure ; l'ajustement vertical de chacune des dents inférieures de telle manière que les pointes incisives des dents antérieures inférieures et les pointes cuspides buccales des dents postérieures inférieures se trouvent sensiblement dans le même plan occlusal et sont inclinées selon des angles définis ; l'ajustement de la configuration de l'arcade inférieure portant des dents pour fournir une configuration finale de la mâchoire inférieure en positionnant dans le sens lèvre/langue les dents inférieures pour placer les pointes incisives et les pointes cuspides buccales de ces dents sur un arc lisse dans le plan occlusal, les dents adjacentes étant au contact les unes des autres ; et extraire une configuration finale des dents supérieures dans laquelle les dents postérieures ont leur sillon central ou leur crête marginale placées horizontalement sur la configuration finale de la mâchoire inférieure portant des dents et verticalement sur le plan occlusal ; les dents antérieures ont leur pointes incisives placées sous le plan occlusal pour obtenir des chevauchements prédéterminés et sont horizontalement décalés vers les lèvres par rapport à la configuration finale de la mâchoire inférieure portant des dents de manière à établir un espace prédéterminé entre les faces linguales des dents antérieures inférieures et leur face labiale ; la conception de l'appareil comprend l'étape consistant à calculer une configuration de crochet pour les crochets individuels des dents supérieures et inférieures comprenant l'angle et la profondeur d'une fente dans chaque crochet, et à calculer une forme pour l'arc dentaire inférieur et supérieur, sur la base des positions finales calculées des dents, des plans prédéterminés des arcs dentaires supérieurs et inférieurs, des formes des dents et des positions de connexion et la fabrication de l'appareil comprend les étapes consistant à fabriquer des arcs dentaires supérieur et inférieur correspondant aux formes d'arc dentaires calculées ; et fabriquer des crochets correspondant aux configurations calculées de crochets.

20. Procédé selon l'une quelconque des revendications précédentes, comprenant les étapes consistant à fournir les critères décrivant les distances séparant les dents prises individuellement de l'axe de pivotement de la mâchoire inférieure ; dans lequel l'extraction de la position finale des dents comprend les étapes consistant à calculer à partir des critères et des données de la forme des dents une composante de la ligne cuspide ; et ajuster verticalement les cuspides supérieures et inférieures de telle manière que leurs pointes se retrouvent respectivement en dessous et au-dessus du plan occlusal à une distance ayant une relation prédéterminée avec la ligne cuspide calculée.

21. Procédé selon la revendication 20 quand elle dépend de la revendication 19, dans lequel l'extraction de la configuration finale des dents supérieures comprend l'extraction de la configuration dans laquelle les dents antérieures supérieures présentent des pointes incisives positionnées sous le plan occlusal de manière à obtenir un chevau-

chement ayant une relation prédéterminée avec la ligne cuspide calculée.

22. Procédé selon soit la revendication 20 soit la revendication 21, dans lequel l'étape de calcul de la composante de la ligne cuspide comprend les étapes consistant à identifier les paires occlusales des dents postérieures supérieures et inférieures respectives du patient, et à déterminer pour chaque paire à partir des données numérisées de la forme des dents la distance verticale séparant le point le plus haut du point le plus bas de la dent supérieure de la paire quand les mâchoires sont serrées ; ajuster chaque distance verticale déterminée selon un facteur se rapportant proportionnellement à la distance séparant chaque paire de l'axe de pivotement et sélectionner la distance verticale ajustée la plus grande, calculer, à partir des données numérisées, les positions finales des dents mandibulaires du patient auxquelles les points les plus hauts de ces dents se trouvent en position verticale sur une surface occlusale approximativement plate ; et calculer les positions finales des cuspides supérieures et inférieures du patient passant respectivement en dessous et au-dessus de la surface occlusale.

23. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre les étapes consistant à concevoir un appareil orthodontique et à fabriquer un système comprenant un sous-système d'introduction de données destiné aux données d'entrée numérisées des formes anatomiques mesurées et générer des signaux d'entrée acheminant les données d'entrée numérisées, un sous-système de traitement de données pour traiter les signaux d'entrée numérisés et générer, en réponse à ceux-ci, des signaux de sortie acheminant les signaux de commande et un sous-système de fabrication des pièces de l'appareil, comprenant la machine de fabrication, pour fabriquer, en réponse aux signaux de sortie, un appareil orthodontique sur mesure pour le traitement du patient en mettant ses dents en positions finales préférées ; générer, avec le sous-système de traitement de données, à partir de l'arcade extraite, des signaux de sortie pour commander le sous-système de fabrication des pièces de l'appareil pour fabriquer l'appareil orthodontique sur mesure ; et fabriquer avec le sous-système de fabrication des pièces de l'appareil, en réponse au signal de sortie et selon les signaux de commande, l'appareil orthodontique sur mesure présentant la configuration sur mesure.

24. Procédé selon la revendication 23, dans lequel l'appareil orthodontique sur mesure comprend un arc dentaire ayant une forme précise se rapportant mathématiquement à l'arcade squelettique du sillon mandibulaire ; le sous-système de fabrication des pièces de l'appareil comprend un appareil à plier le fil sensible aux signaux acheminés par le signal de sortie ; et le signal de sortie comprend une série de signaux de commande pour actionner l'appareil à plier le fil pour assurer l'alimentation en fil et plier ce dernier selon la configuration d'arcade sur mesure afin d'assurer la connexion de l'arc dentaire avec les dents au niveau des points respectifs de connexion.

25. Procédé selon la revendication 24, dans lequel les données d'entrée numérisées contiennent une information à partir de laquelle le point de connexion de l'appareil et la pente de la surface au niveau de ce point de connexion peuvent être extraits ; l'appareil orthodontique sur mesure comprend une pluralité de crochets, un par point de connexion à la dent, chacun ayant une base susceptible d'être fixée sur le point de connexion respectif et une fente susceptible d'être reliée à l'arc dentaire ; le sous-système de fabrication des pièces de l'appareil comprend un appareil de fabrication de crochets sensible aux signaux de commande acheminés par le signal de sortie ; et le signal de sortie comprend une série de signaux de commande pour actionner l'appareil de fabrication de crochets afin de fabriquer chaque crochet doté d'une fente pour l'arc dentaire positionnée par rapport à la base de manière porter et orienter un point de l'arc dentaire par rapport au point de connexion de la dent respective pour transférer la force entre l'un à l'autre pour contraindre la dent à prendre sa position finale.

26. Procédé selon la revendication 25, dans lequel les données d'entrée numérisées contiennent une information concernant le contour de la surface de la dent ; l'appareil orthodontique sur mesure comprend, pour chaque crochet, un gabarit pour la mise en place du crochet, ce gabarit ayant une surface servant à positionner de manière unique le gabarit sur la surface de la dent et à positionner le crochet sur celle-ci au niveau de son point de connexion ; le sous-système de fabrication des pièces de l'appareil comprend un appareil pour fabriquer les gabarits pour assurer la mise en place des crochets, cet appareil étant sensible aux signaux de commande acheminés par le signal de sortie ; et le signal de sortie comprend une série de signaux de commande pour actionner cet appareil de fabrication des gabarits pour la mise en place des crochets.

27. Procédé selon soit la revendication 25 soit la revendication 26, dans lequel la fabrication de l'appareil comprend les étapes consistant à utiliser une pluralité d'ébauches de crochet ; et à façonner un crochet à partir de ces ébauches en formant, dans chacun de ces crochets, une fente pour l'arc dentaire de telle sorte que chaque fente se trouve dans le plan de l'arc dentaire quand le crochet est monté sur le point de connexion d'une dent, celle-ci étant dans sa position finale calculée.

28. Procédé selon la revendication 27, dans lequel l'extraction de l'arcade comprend l'étape consistant à extraire à partir des données numérisées une arcade squelettique représentant mathématiquement la forme de l'os cortical du patient par une équation continue lissée extraite des points numérisés correspondant aux contours de l'os cortical du patient et représenter l'équation de l'arcade par une série d'arcs de cercle tangentiels successifs ; la découpe de la fente du crochet comprend l'étape consistant à former la fente à une profondeur définie par l'intersection de l'équation de l'arcade avec le crochet, quand le crochet est monté sur le point de connexion d'une dent, celle-ci étant dans sa position finale calculée, cette découpe de la fente comprenant également à former le fond de cette fente selon la courbure du rayon de l'arc de cercle venant en intersection avec la courbe de l'équation de l'arcade.

29. Procédé selon l'une quelconque des revendications précédentes, dans lequel, pour maintenir un espacement optimal de l'appareil par rapport aux gencives d'un patient et un espace libre vis à vis des dents de la mâchoire opposée du patient, l'établissement de la position des connexions comprend les étapes consistant à numériser la géométrie des parties de l'appareil ; calculer à partir des données numérisées de la forme des dents les relations des points sur les surfaces des dents des mâchoires opposées du patient ; calculer à partir des données numérisées les emplacements des surfaces des dents d'une mâchoire de patient sur lesquels l'appareil doit être fixé pour maintenir un espacement optimal entre l'appareil et les gencives et un espace libre vis à vis des dents de la mâchoire opposée du patient ; et concevoir la configuration de l'appareil selon les emplacements calculés pour la connexion de l'appareil sur les dents du patient.

30. Procédé selon l'une quelconque des revendications 1 à 23, dans lequel l'appareil orthodontique sur mesure comprend un arc dentaire ; la conception de l'appareil comprend l'étape consistant à extraire des données numériques concernant la forme de l'arc dentaire sur la base au moins en partie de l'arcade extraite ; la production des signaux de commande comprenant l'étape consistant à générer des signaux définissant la forme de l'arc en réponse aux données numériques de cette forme, de telle sorte que, quand elles sont communiquées à un dispositif formant les arcs, ce dispositif produit un arc sur mesure sur la base de l'anatomie de la bouche du patient ; et donner au matériau pour arc dentaire une forme définie en réponse au signal de commande de cet arc dentaire sur mesure.

31. procédé selon la revendication 30, dans lequel la production du signal de commande comprend les étapes consistant à fournir des données sur les propriétés du matériau de l'arc dentaire ; et à générer le signal de commande de pliage de l'arc en réponse à ces données sur les propriétés du matériau.

32. Procédé selon soit la revendication 30 soit la revendication 31, comprenant en outre les étapes consistant à mesurer un intervalle entre deux points situés sur l'arc dentaire fabriqué sur mesure ; calculer un intervalle théorique à partir des données extraites concernant la forme de l'arc dentaire ; comparer l'intervalle mesuré à l'intervalle théorique et signaler le résultat de la comparaison ; et générer le signal de commande de pliage de l'arc en réponse au résultat de la comparaison.

33. Dispositif pour la fabrication sur mesure d'un appareil orthodontique comprenant des moyens (30, 30a, 33, 43, 50, 57) pour mesurer l'anatomie (20-24) de la bouche (18) d'un patient (12) et produire à partir de ces mesures des données numérisées de cette anatomie (26) comprenant des données de la forme de la bouche en trois dimensions représentant les formes de chaque dent du patient prise individuellement, un ordinateur numérique (30b, 30c) comprenant un programme pour extraire une arcade dentaire idéale à partir des données numérisées (26) à l'aide de l'ordinateur (30b) programmé spécialement pour produire un modèle numérisé d'arcade, ce modèle étant au moins en partie dépendant des données numérisées concernant l'anatomie ; extraire avec l'ordinateur, à partir de ces données numérisées (26) et l'arcade numérisée extraite idéale, les positions finales des dents pour espacer de manière mésio-distale les dents le long de l'arcade dentaire idéale extraite et placer les dents par rapport à celle arcade dans des positions et orientations basées au moins en partie sur les données relatives à la forme des dents en trois dimensions pour chaque dent prise individuellement; établir des points de connexion de l'appareil sur chacune des dents d'une pluralité ; établir, à partir des données numérisées de la forme des dents, des points de connexion de l'appareil et des positions finales extraites des dents, une configuration d'appareil telle que l'appareil fabriqué sur mesure selon ces données présente des dimensions permettant d'interconnecter les dents au niveau des points de connexion, ces dents étant en position finale extraite, et produire un code machine (42) contenant les informations géométriques corrélées à la configuration conçue de l'appareil ; et une machine (38, 39, 40, 41) pour fabriquer automatiquement un appareil orthodontique sur mesure (25) en réponse au code machine (42) pour façonner l'appareil (25) selon les informations géométriques de manière à ce qu'il présente la configuration choisie.

34. Dispositif selon la revendication 33, dans lequel la machine de fabrication (38) comprend un dispositif (40) pour former des arcs dentaires comprenant des moyens (66-71) pour donner à un matériau pour arc dentaire (69) une

forme déterminée en réponse à un signal de commande de la forme de cet arc communiqué à ce dispositif ; et le programme comprenant un moyen pour générer un signal de commande de la forme de l'arc en réponse aux données numériques relatives à la forme de l'arc, de telle manière que, quand le signal est communiqué au dispositif pour former des arcs dentaires, ce dispositif produit un arc dentaire (64) correspondant à la forme anatomique de la bouche du patient (18).

35. Dispositif selon la revendication 34, dans lequel les données numériques de la forme de l'arc dentaire comprennent des données concernant la longueur de l'arc corrélées à une composante de la longueur relative aux données numériques extraites de la forme de l'arc dentaire et des données concernant la courbure de l'arc corrélées à une composante des données numériques extraites relatives à la forme de l'arc dentaire fonction de la composante de longueur ; le signal de commande de la forme de l'arc comprend un signal commandant l'alimentation en fil acheminant les données concernant la longueur de ce fil et un signal commandant le pliage du fil acheminant les données relatives à la courbure de celui-ci ; le programme comprend un moyen pour générer le signal commandant l'alimentation en fil et un moyen pour générer un signal commandant le pliage du fil et communiquer les signaux de commande au dispositif formant l'arc dentaire ; et le dispositif (40) formant l'arc dentaire comprend un moyen (68) pour l'alimenter longitudinalement en matériau (69) en réponse au signal de commande et un moyen (70) pour plier transversalement le matériau de l'arc dentaire (69) fourni par l'alimentation (68) en réponse au signal commandant le pliage du fil, celui-ci étant synchrone avec la fourniture du matériau de l'arc dentaire (69).

36. Dispositif selon la revendication 34, dans lequel les données numériques relatives à la forme de l'arc dentaire sont une représentation numérique d'une série de segments de fil reliés, chacun ayant une composante de longueur et une composante de courbure ; et le dispositif formant l'arc dentaire comprend un moyen pour alimenter longitudinalement une série de longueurs de matériau d'arc dentaire correspondant aux composantes respectives de longueur de fil selon les données de longueur de fil et un moyen (70) pour plier chaque longueur fournie de matériau d'arc dentaire (69) selon une courbure correspondant à la composante respective de courbure du fil correspondant aux données de courbure du fil.

37. Dispositif selon la revendication 36, dans lequel chaque segment de fil à la forme d'un arc de cercle, sa composante de longueur représentant un longueur tangentielle de matériau de l'arc dentaire et sa composante de courbure représentant un rayon constant de la courbure du matériau sur la longueur tangentielle de l'arc ; et le moyen d'alimentation (68) comprend un moyen pour fournir longitudinalement une série de longueurs tangentielles du matériau de l'arc dentaire (69) et le moyen de pliage (70) comprend un moyen pour plier chaque longueur fournie de segment d'arc dentaire selon un rayon constant correspondant aux données de courbure du fil.

38. Dispositif selon la revendication 37, dans lequel le moyen d'alimentation (68) sert à fournir de manière séquentielle une série de longueurs du matériau de l'arc dentaire égales aux composantes de longueur des arcs de cercle, en réponse au signal d'alimentation en fil, sur un trajet longitudinal ; le moyen de pliage (70) comprend un élément de pliage (70b) susceptible d'être déplacé en réponse à un signal de pliage du fil transversal par rapport au trajet pour imprimer une déflexion de pliage transversale par rapport au segment et un capteur en position transversale pou reproduire un signal de retour sensible à la déflexion ; et l'ordinateur (30b, 30c) comprend un moyen pour modifier le signal commandant le pliage du fil en réponse au signal de retour pour assurer une commande en boucle fermée de l'élément de pliage.

39. Dispositif selon l'une quelconque des revendications 36 à 38, comprenant en outre un moyen pour mesurer un intervalle de l'arc dentaire produit sur mesure (64) entre des points situés sut les premier et dernier segments de la série de cet arc ; le programme comprend un moyen pour calculer un intervalle de l'arc dentaire conçu à partir des données extraites de la forme de cet arc ; un moyen pour comparer l'intervalle de l'arc dentaire mesuré et celui de l'arc dentaire conçu et pour mettre en mémoire les résultats de la comparaison ; et le programme servant à générer le signal de commande de la forme de l'arc en réponse au résultat mémorisé de la comparaison.

40. Dispositif selon l'une quelconque des revendications 36 à 39, dans lequel le programme comprend un moyen en communication avec le moyen générant le signal commandant la forme du fil pour recevoir des données relatives aux propriétés du matériau de l'arc dentaire et modifier ce signal selon ces données pour compenser les propriétés élastiques du matériau.

41. Dispositif selon l'une quelconque des revendications 33-40, dans lequel la machine de fabrication (38) comprend un appareil (39) formant les crochets comprenant un support (73) sur lequel se trouve un moyen pour monter l'ébauche de crochet (80) pour fabrication ; un moyen (75-77) pour façonner au moins une surface de l'ébauche

(80) montée sur le support (73) en réponse à un signal de commande de la machine communiqué à celle-ci en réponse au signal de commande, comprenant le moyen (77) pour façonner l'ébauche de crochet (80) monté sur le support (73) afin de produire un crochet ayant une fente présentant, avec la surface de montage de la base de son crochet, une relation géométrique calculée.

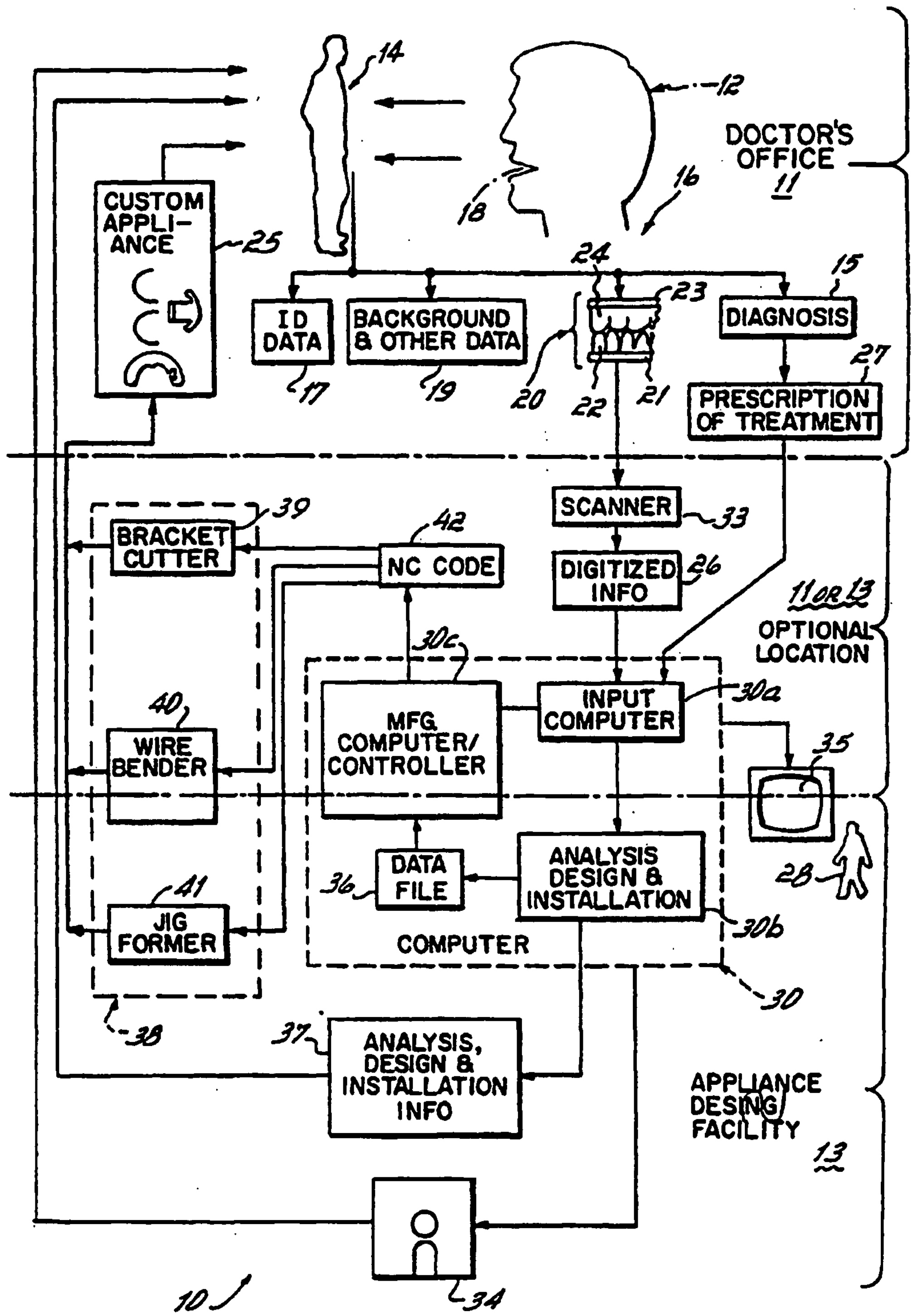
42. Dispositif selon la revendication 41, dans lequel chaque fente comprend des côtés supérieur et inférieur globalement parallèles définissant une inclinaison de cette fente et une base à son extrémité la plus proche de la base du crochet définissant la position de la fente ; chaque relation géométrique calculée d'une fente avec la surface de montage d'un crochet comprend l'inclinaison de la fente et la position de celle-ci par rapport à la surface de montage ; le signal de commande de la machine généré achemine des instructions commandant la machine pour que le moyen de façonnage (75-77) donne forme à l'ébauche de crochet (80) pour produire un crochet ayant une fente (80b) présentant l'inclinaison et la position calculées par rapport à la surface de montage ; la fente (80b) de chaque crochet est adaptée pour recevoir un arc dentaire (64) ayant une courbure sur mesure voisine de la dent sur laquelle le crochet doit être fixé ; chaque relation géométrique calculée de la fente avec la surface de montage d'un crochet comprend une courbure du fond de la fente se conformant à la courbure sur mesure de l'arc dentaire (64) voisin ; et le signal de commande de la machine généré achemine des instructions commandant la machine pour que le moyen de façonnage donne forme à l'ébauche de crochet (80) pour produire un crochet ayant une fente dont le fond présente la courbure calculée.

43. Dispositif selon soit la revendication 41 soit la revendication 42, dans lequel le moyen de façonnage (75-77) comprend un moyen (77) pour découper une fente (80b) en réponse au signal de commande.

44. Dispositif selon l'une quelconque des revendications 41 à 43, dans lequel le support (73) et le moyen de façonnage (75-77) sont montés sur une base (72) ; et le dispositif comprend en outre un moyen (74) pour orienter de manière angulaire le support (73) par rapport à la base (72) et au moyen de façonnage (75-77), et un moyen (75,76) pour déplacer par translation le moyen de mise en forme (77) par rapport à la base (72) et au support (73), en réponse au signal de commande.

45. Dispositif selon l'une quelconque des revendications 33 à 44, dans lequel la machine de fabrication (38) comprend un dispositif (41) pour façonner un gabarit incluant un moyen (81) pour former un gabarit de mise en place d'un appareil orthodontique sur mesure sur la dent d'un patient, ce moyen (81) formant les contours de la surface d'un matériau (83) d'une ébauche de gabarit en réponse à un signal de commande ; les moyens de mesure (30, 30a, 33, 43, 50, 57) comprennent un moyen pour fournir un enregistrement numérisé des formes des dents d'un patient (12) et, par rapport à l'enregistrement de la forme des dents, des emplacements de points de connexion de l'appareil sur les surfaces des dents ; le programme comprend un moyen pour calculer, à partir de l'enregistrement de la forme numérisée des dents et des points de connexion, la géométrie du gabarit définissant une surface pour la mise en place du gabarit épousant une partie unique de la surface externe de la couronne de la dent et définissant une surface de prise de l'appareil ayant le même emplacement par rapport à la surface d'engagement du gabarit que celui de la partie de la surface externe par rapport au point de connexion avec la dent ; et le moyen de production comprend un moyen pour générer un signal de commande de la machine acheminant des instructions commandant la machine pour produire un gabarit (82) selon la géométrie calculée.

46. Dispositif selon la revendication 45, dans lequel l'appareil comprend une pluralité de crochets (80), un par connexion sur chaque point de connexion avec la dent ; l'appareil comprend en outre un moyen pour fournir des données numérisées de forme d'une surface externe de chaque crochet devant être connecté au point de connexion ; et dans lequel le moyen de calcul de la géométrie du gabarit comprend un moyen pour définir la surface de prise du gabarit et de l'appareil pour correspondre, en réponse aux données numérisées de la forme des crochets, à la géométrie établie de l'appareil.


14
12
DOCTOR'S OFFICE
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16
18
CUSTOM APPLI-ANCE
25
24
23
15
ID DATA
BACKGROUND & OTHER DATA
DIAGNOSIS
27
17
19
20
22
21
PRESCRIPTION OF TREATMENT
SCANNER
33
39
42
BRACKET CUTTER
NC CODE
DIGITIZED INFO
26
11 OR 13
OPTIONAL LOCATION
30c
40
INPUT COMPUTER
30a
MFG. COMPUTER/ CONTROLLER
35
WIRE BENDER
28
ANALYSIS DESIGN & INSTALLATION
DATA FILE
36
41
JIG FORMER
30b
COMPUTER
30
38
37
ANALYSIS, DESIGN & INSTALLATION INFO
APPLIANCE DESING FACILITY
13
10
34

FIG. 1

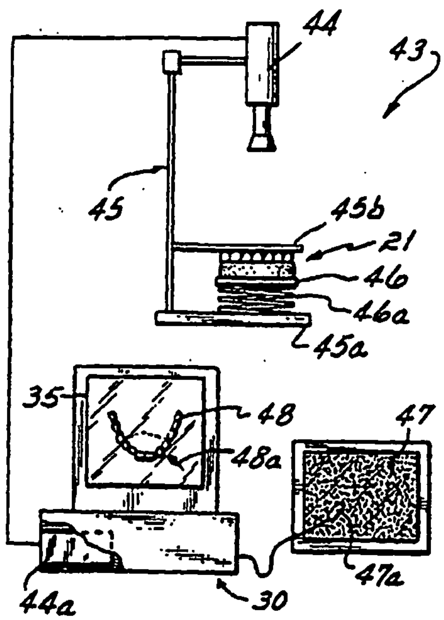



FIG. 1A

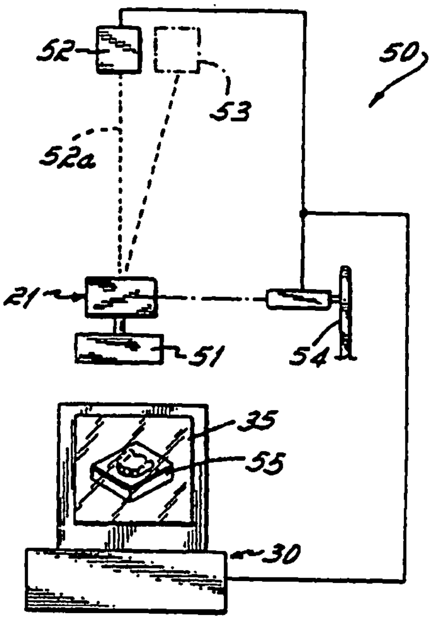



FIG. 1B

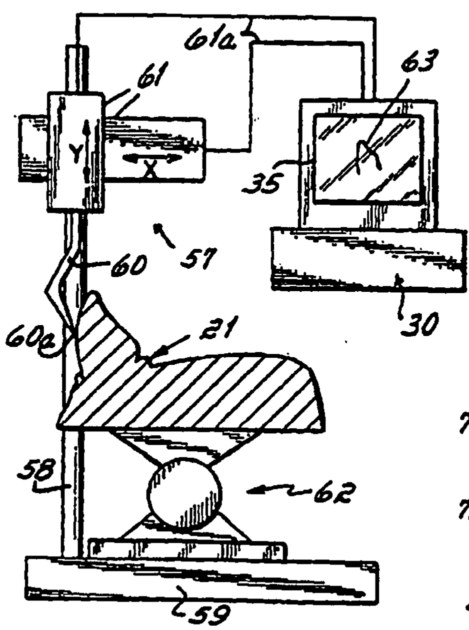



FIG. 1C

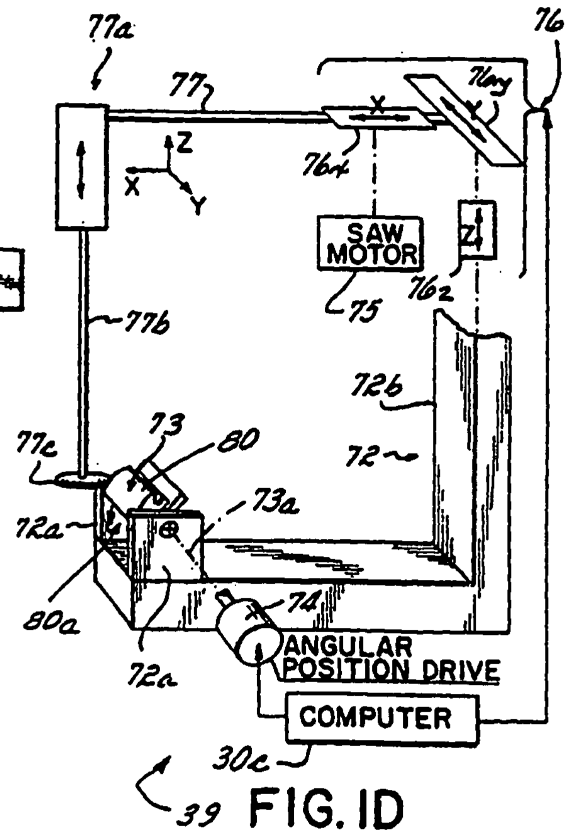
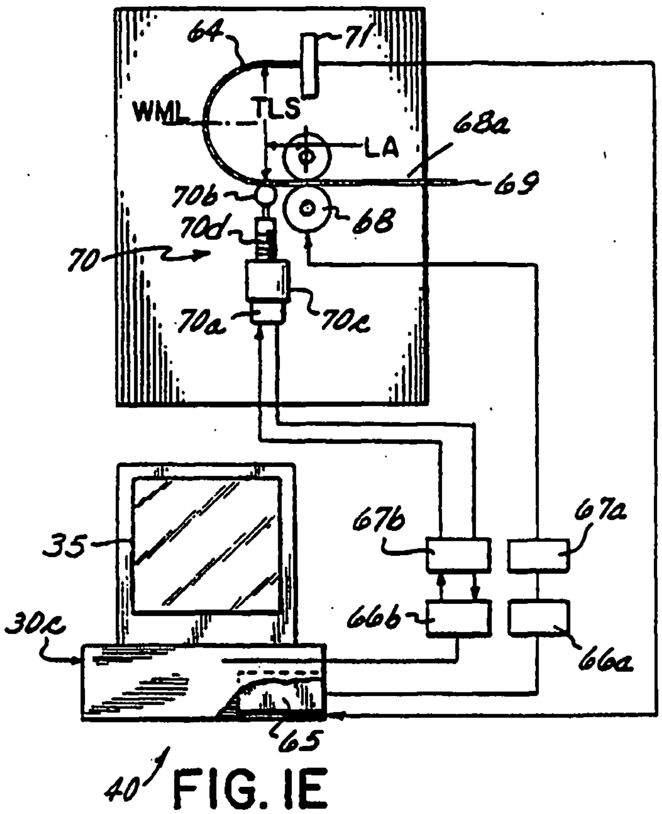



FIG. 1D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LA
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70b
70d
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70c
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67a
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66b
30c
66a
65
40

FIG. 1E

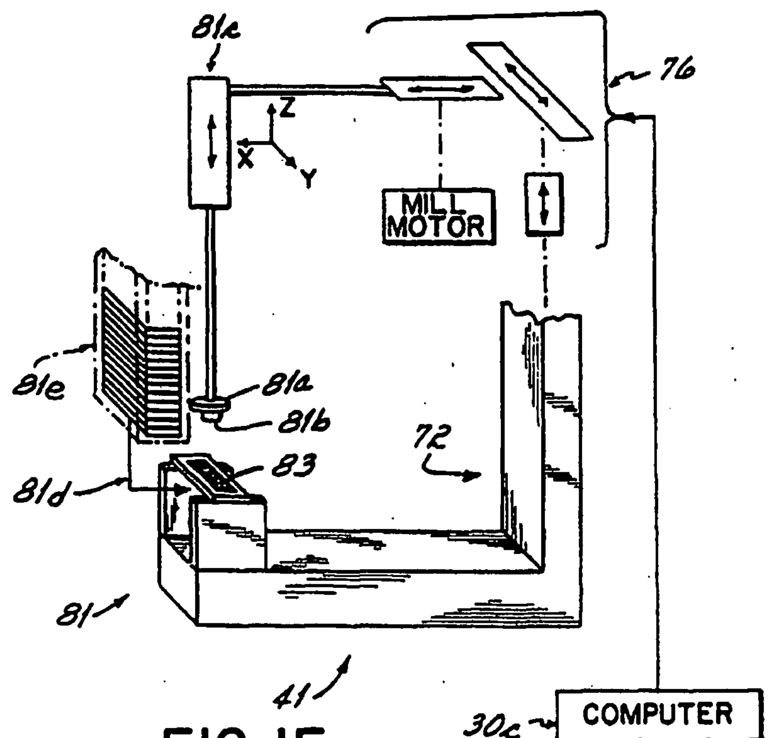

81c
76
Z
X
Y
MILL MOTOR
81e
81a
81b
72
83
81d
81
41
COMPUTER
30c

FIG. 1F

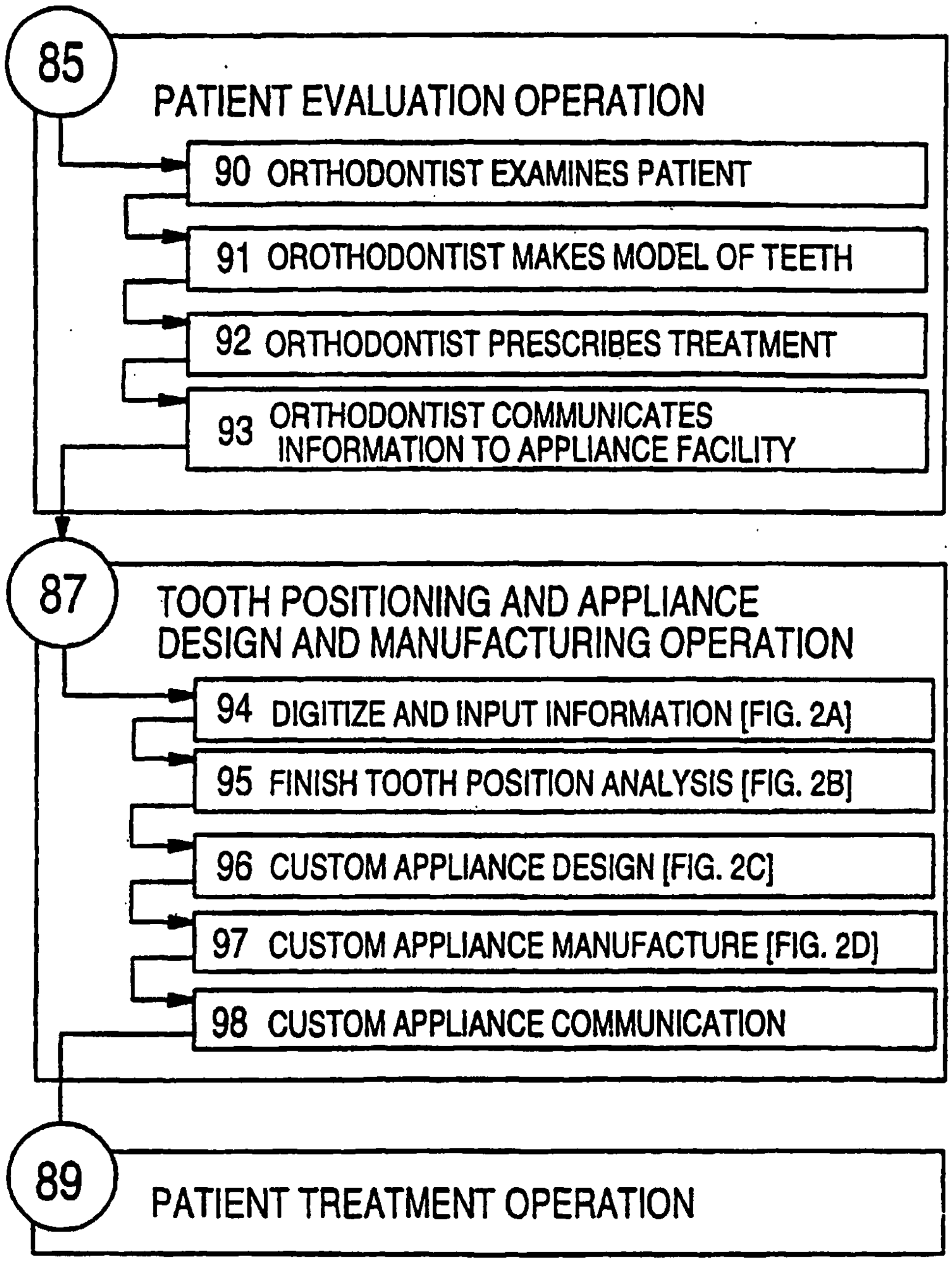

85
PATIENT EVALUATION OPERATION
90 ORTHODONTIST EXAMINES PATIENT
91 OROTHODONTIST MAKES MODEL OF TEETH
92 ORTHODONTIST PRESCRIBES TREATMENT
93 ORTHODONTIST COMMUNICATES INFORMATION TO APPLIANCE FACILITY
87
TOOTH POSITIONING AND APPLIANCE DESIGN AND MANUFACTURING OPERATION
94 DIGITIZE AND INPUT INFORMATION [FIG. 2A]
95 FINISH TOOTH POSITION ANALYSIS [FIG. 2B]
96 CUSTOM APPLIANCE DESIGN [FIG. 2C]
97 CUSTOM APPLIANCE MANUFACTURE [FIG. 2D]
98 CUSTOM APPLIANCE COMMUNICATION
89
PATIENT TREATMENT OPERATION

FIG. 2

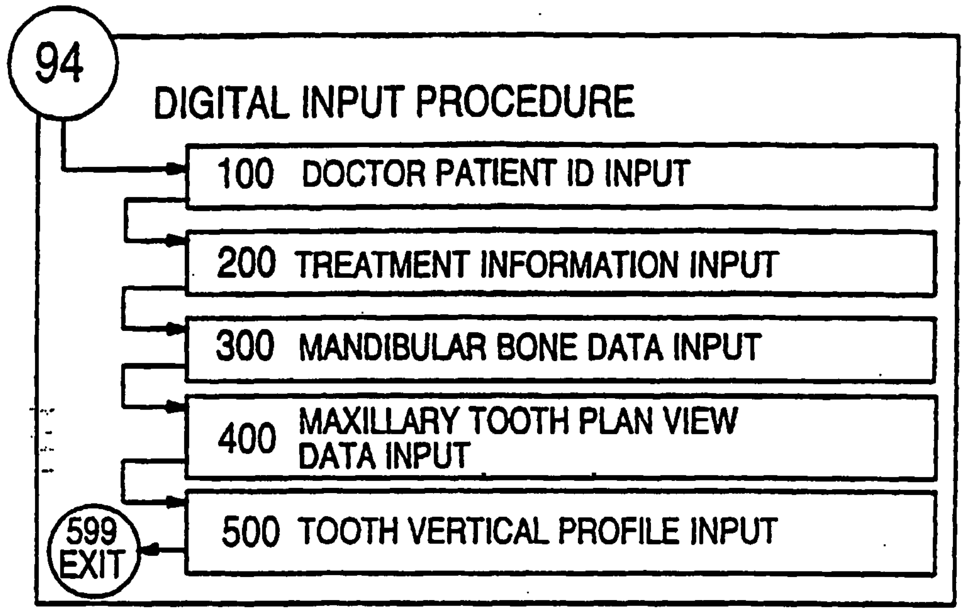

94
DIGITAL INPUT PROCEDURE
100 DOCTOR PATIENT ID INPUT
200 TREATMENT INFORMATION INPUT
300 MANDIBULAR BONE DATA INPUT
400 MAXILLARY TOOTH PLAN VIEW DATA INPUT
500 TOOTH VERTICAL PROFILE INPUT
599 EXIT

FIG. 2A

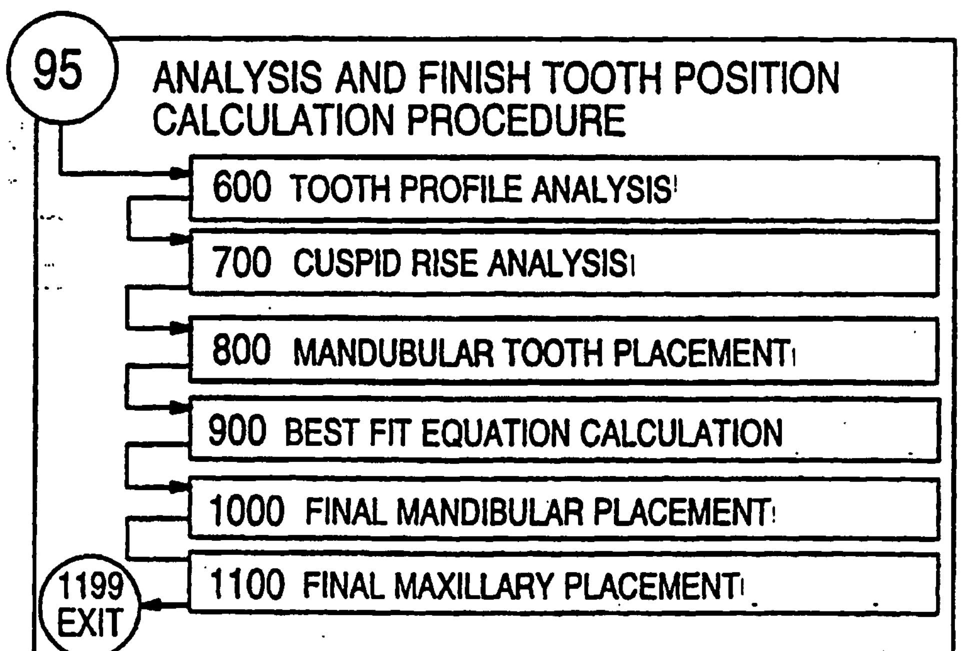

95
ANALYSIS AND FINISH TOOTH POSITION CALCULATION PROCEDURE
600 TOOTH PROFILE ANALYSIS
700 CUSPID RISE ANALYSIS
800 MANDUBULAR TOOTH PLACEMENT
900 BEST FIT EQUATION CALCULATION
1000 FINAL MANDIBULAR PLACEMENT
1100 FINAL MAXILLARY PLACEMENT
1199 EXIT

FIG. 2B

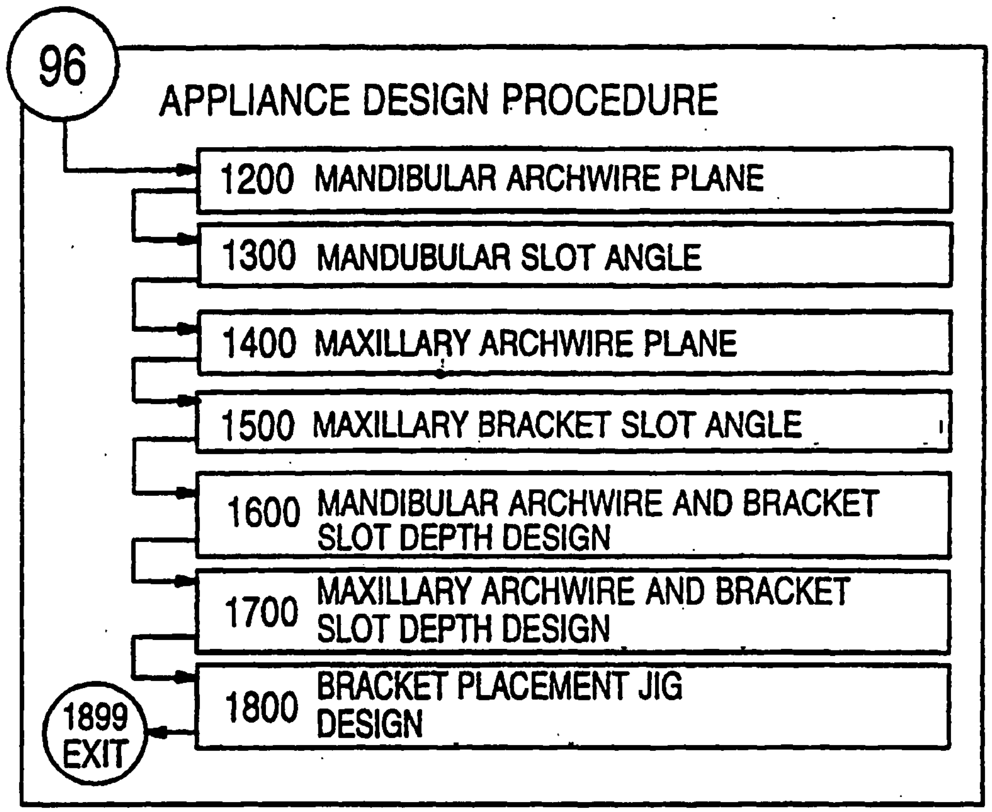

96
APPLIANCE DESIGN PROCEDURE
1200 MANDIBULAR ARCHWIRE PLANE
1300 MANDUBULAR SLOT ANGLE
1400 MAXILLARY ARCHWIRE PLANE
1500 MAXILLARY BRACKET SLOT ANGLE
1600 MANDIBULAR ARCHWIRE AND BRACKET SLOT DEPTH DESIGN
1700 MAXILLARY ARCHWIRE AND BRACKET SLOT DEPTH DESIGN
1800 BRACKET PLACEMENT JIG DESIGN
1899 EXIT

FIG. 2C

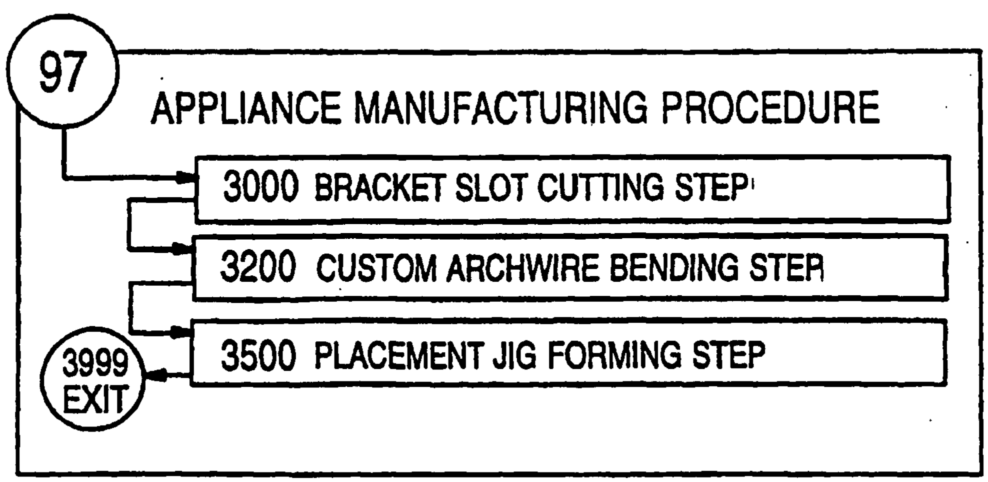

97
APPLIANCE MANUFACTURING PROCEDURE
3000 BRACKET SLOT CUTTING STEP
3200 CUSTOM ARCHWIRE BENDING STEP
3500 PLACEMENT JIG FORMING STEP
3999 EXIT

FIG. 2D

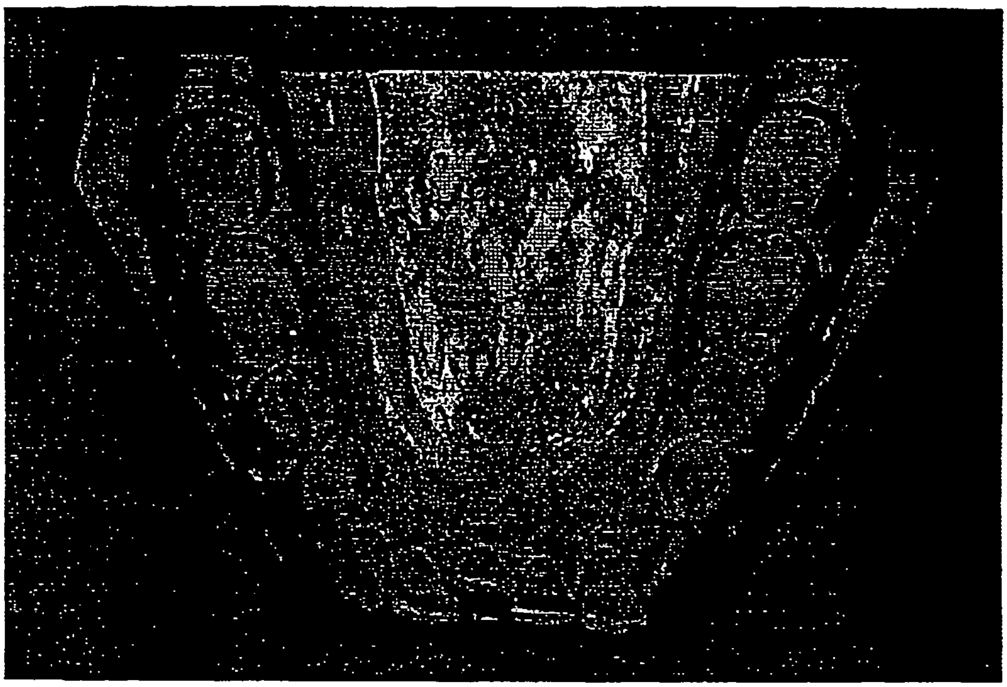
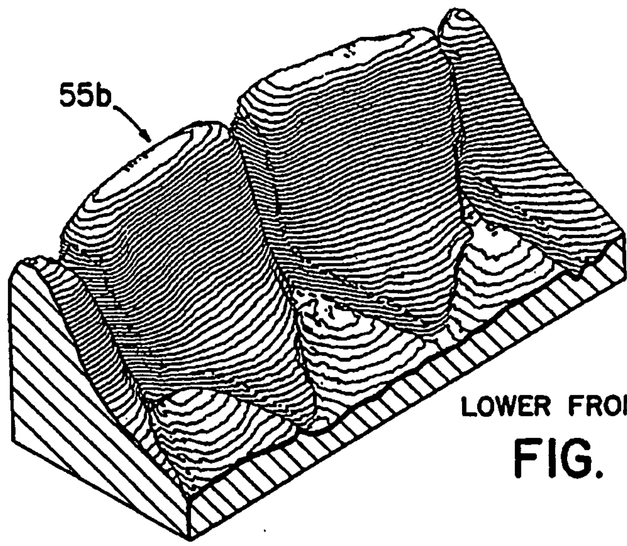
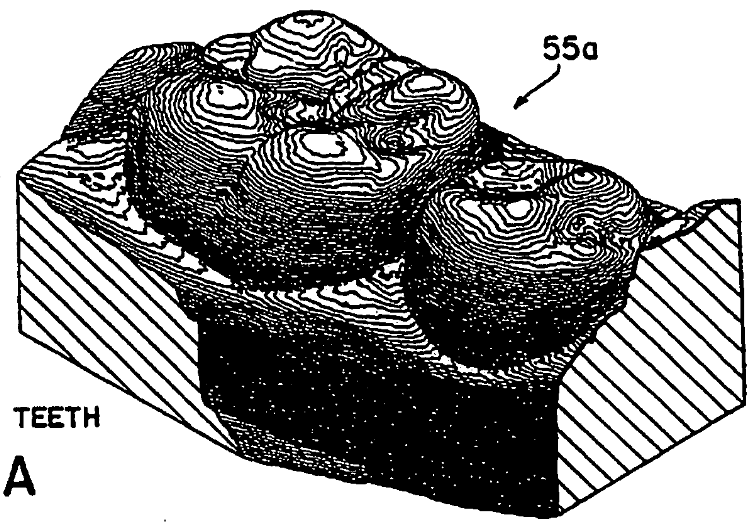


FIG. 3



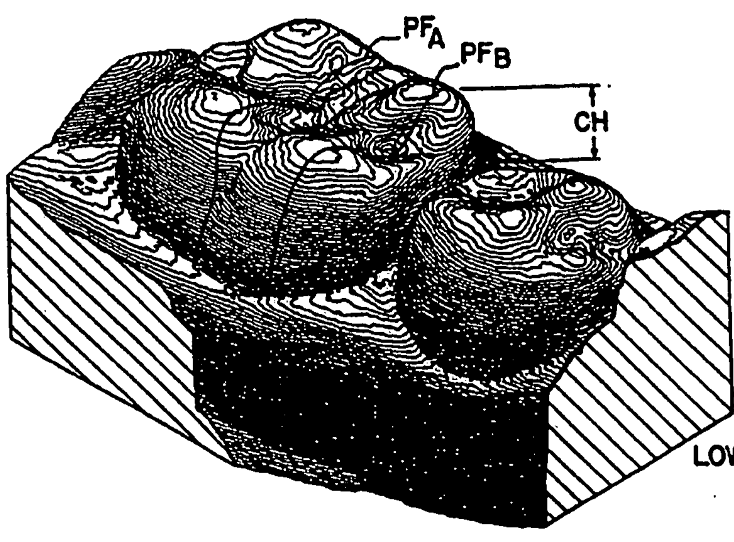

LOWER FRONT TEETH

FIG. 3B




LOWER RIGHT TEETH

FIG. 3A




LOWER RIGHT TEETH

FIG. 6

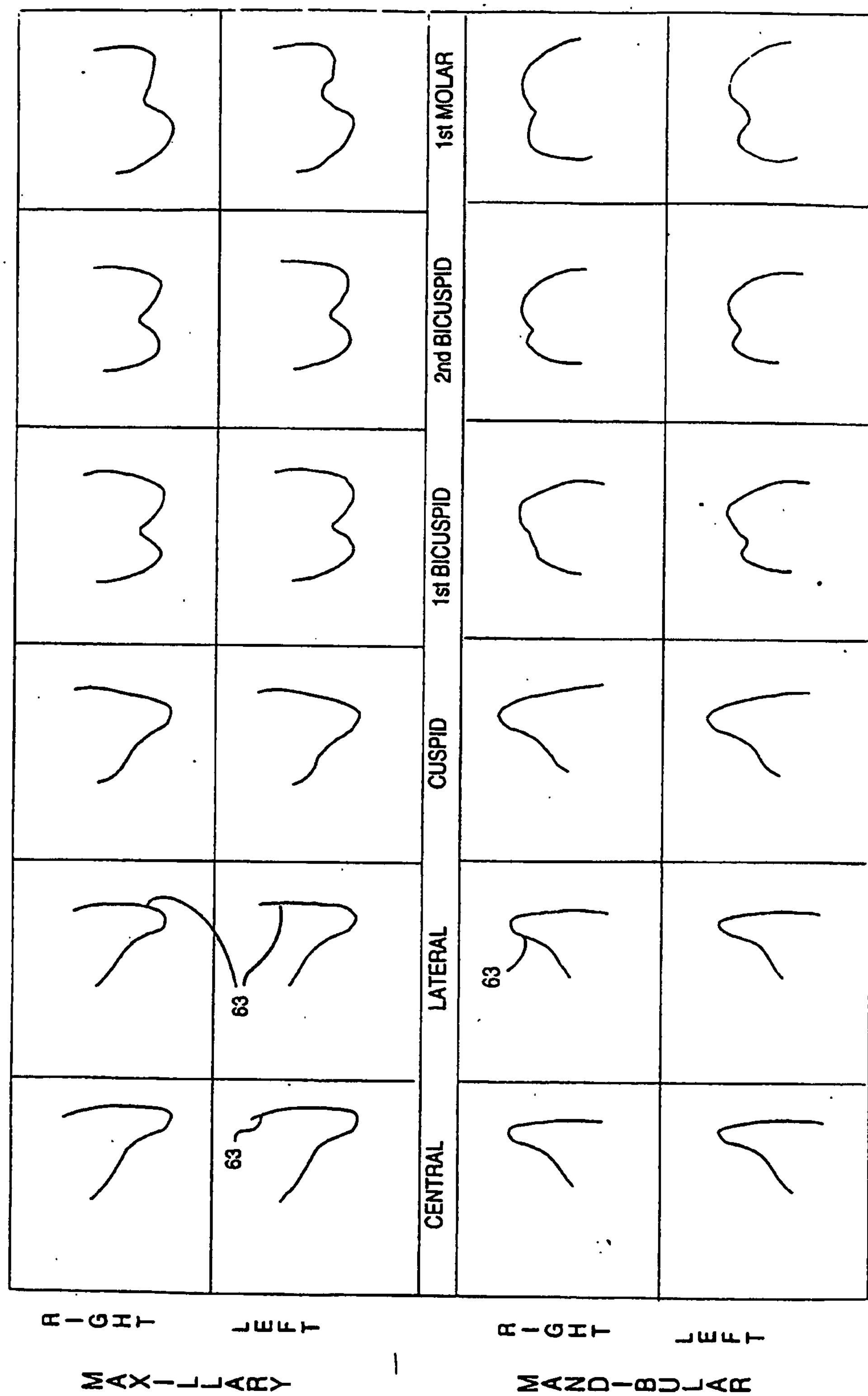
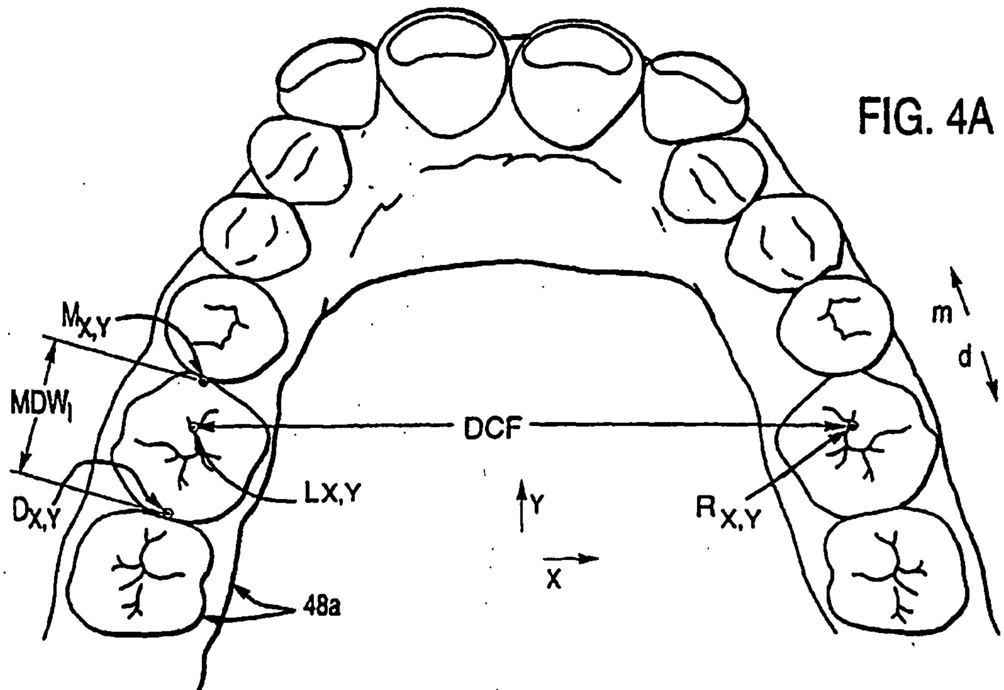
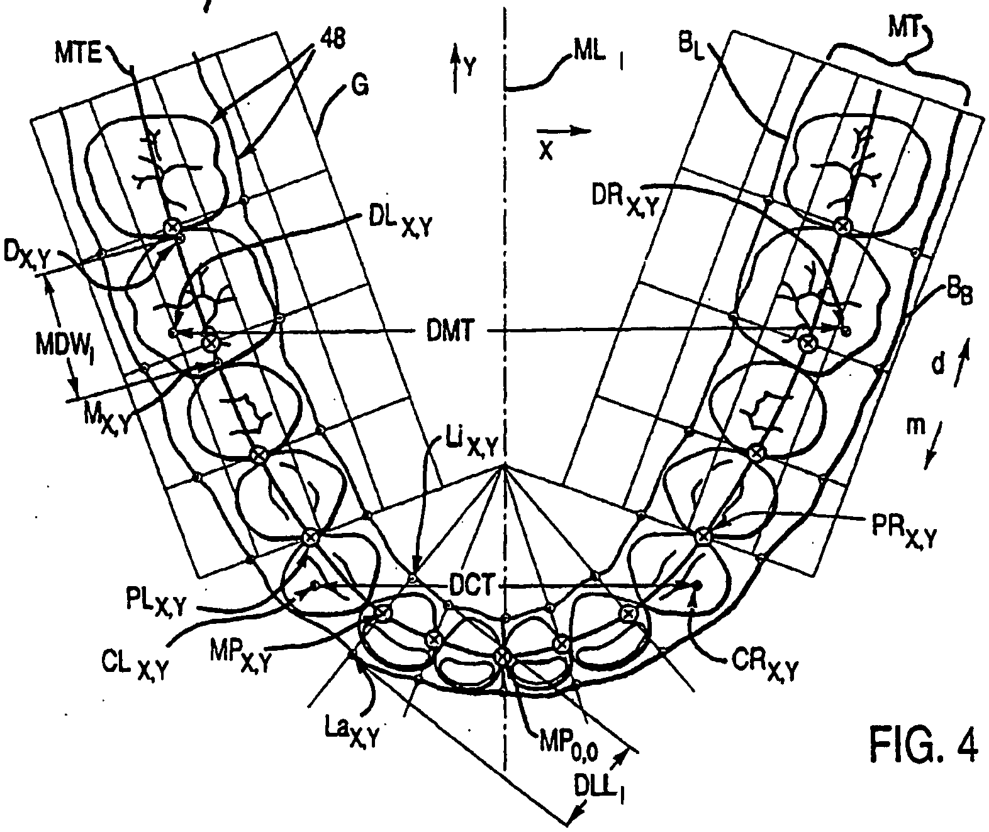

1st MOLAR
2nd BICUSPID
1st BICUSPID
CUSPID
LATERAL
CENTRAL
63
63
63
RIGHT
LEFT
MAXILLARY
RIGHT
LEFT
MANDIBULAR

FIG.3C



$M_{X,Y}$
$MDW_I$
DCF
$D_{X,Y}$
$LX,Y$
Y
$R_{X,Y}$
X
48a
m
d

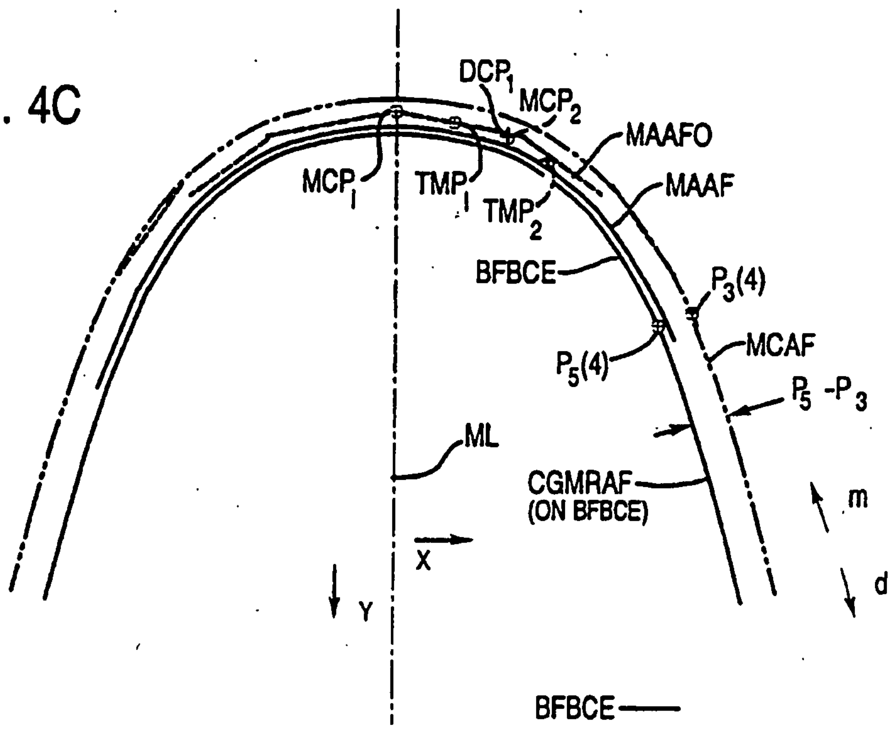

FIG. 4A



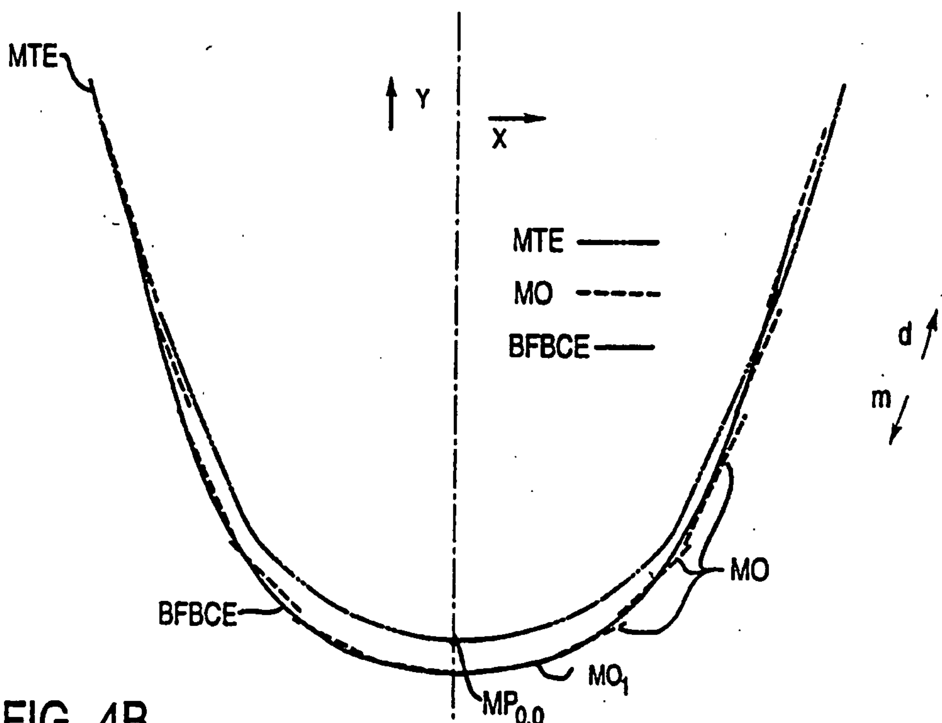
MTE
48
G
Y
$ML_I$
$B_L$
MT
X
$DL_{X,Y}$
$DR_{X,Y}$
$D_{X,Y}$
$B_B$
$MDW_I$
DMT
d
$M_{X,Y}$
m
$Li_{X,Y}$
$PR_{X,Y}$
$PL_{X,Y}$
DCT
$CL_{X,Y}$
$MP_{X,Y}$
$CR_{X,Y}$
$La_{X,Y}$
$MP_{0,0}$
$DLL_I$


FIG. 4

FIG. 4C



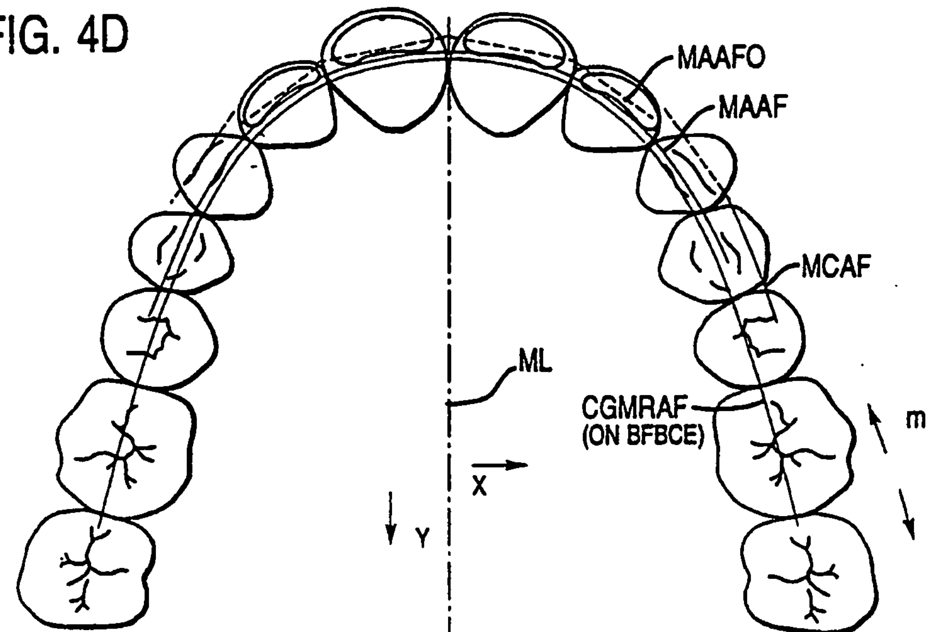
DCP1
MCP2
MAAFO
MAAF
MCP1
TMP1
TMP2
BFBCE
P3(4)
P5(4)
MCAF
P5 -P3
ML
CGMRAF
(ON BFBCE)
m
d
X
Y
BFBCE

MTE
Y
X
MTE
MO
BFBCE
d
m
MO
BFBCE
MO1
MP0,0


FIG. 4B

FIG. 4D


MAAFO
MAAF
MCAF
ML
CGMRAF
(ON BFBCE)
m
d
X
Y

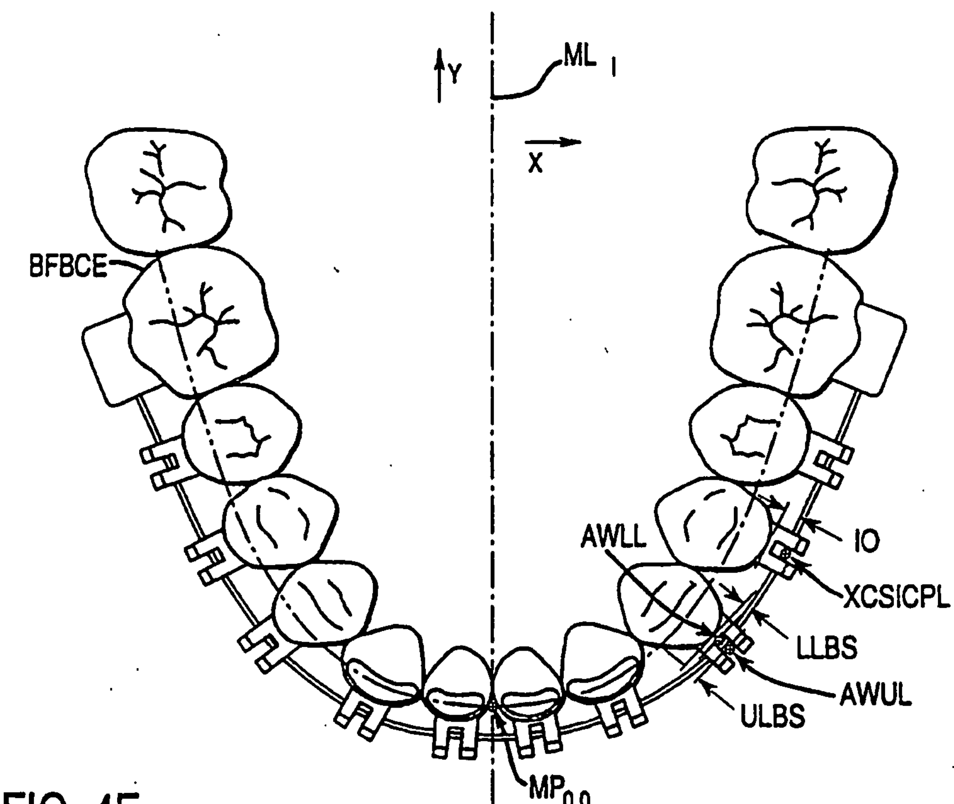

Y
ML I
X
BFBCE
AWLL
IO
XCSICPL
LLBS
AWUL
ULBS
$MP_{0,0}$

FIG. 4E

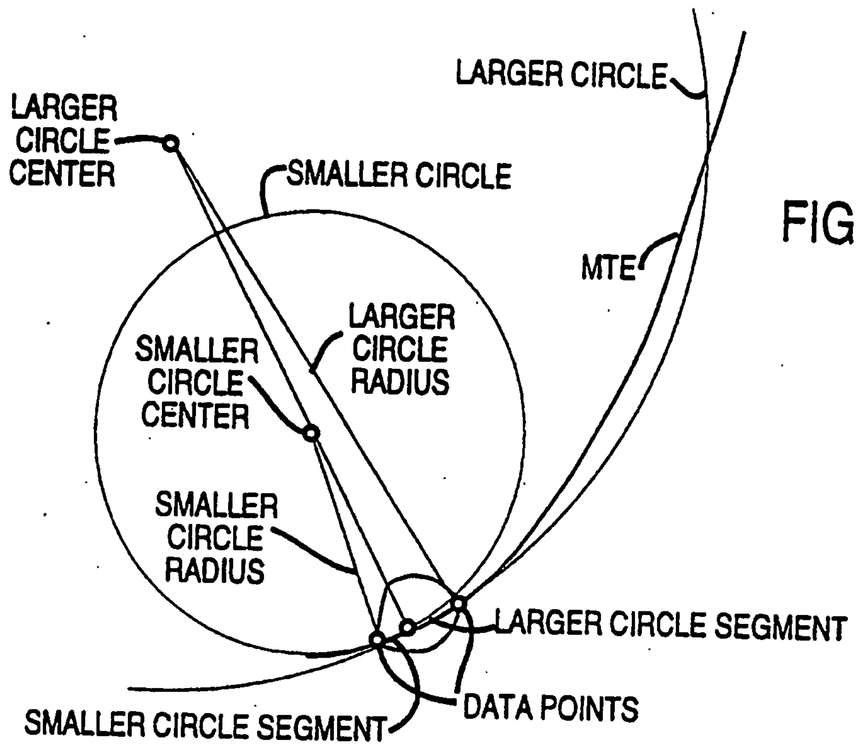

LARGER CIRCLE
LARGER CIRCLE CENTER
SMALLER CIRCLE
MTE
LARGER CIRCLE RADIUS
SMALLER CIRCLE CENTER
SMALLER CIRCLE RADIUS
LARGER CIRCLE SEGMENT
DATA POINTS
SMALLER CIRCLE SEGMENT

FIG. 5

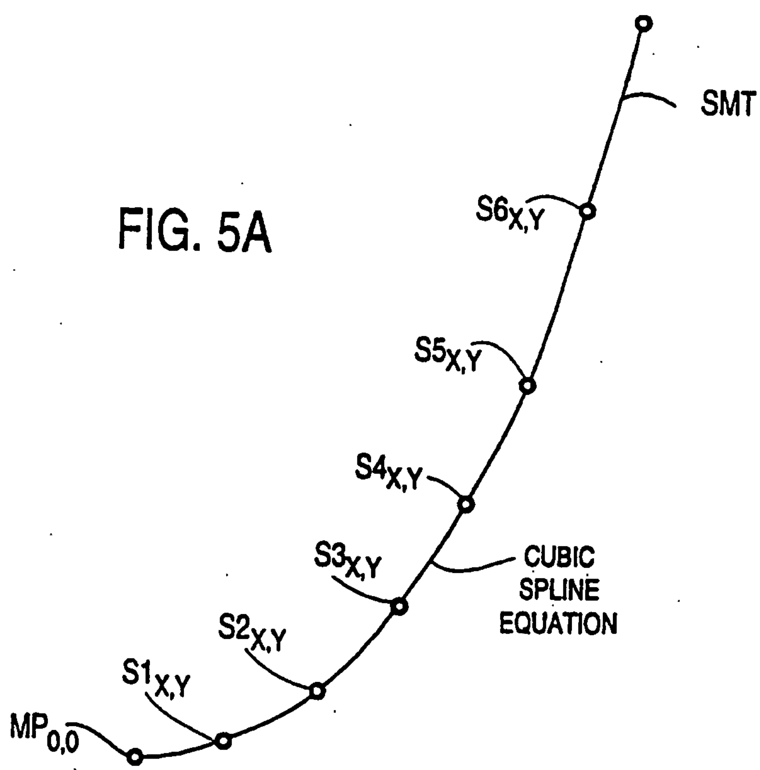

SMT
S6X,Y
S5X,Y
S4X,Y
S3X,Y
CUBIC SPLINE EQUATION
S2X,Y
S1X,Y
MP0,0

FIG. 5A

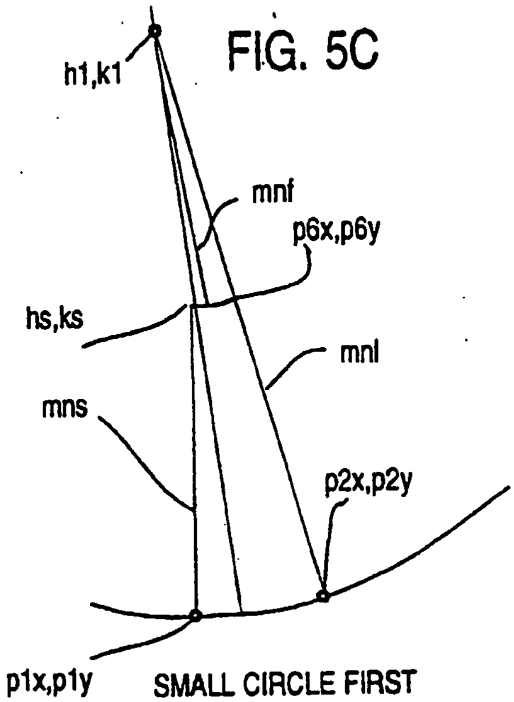



FIG. 5C

SMALL CIRCLE FIRST

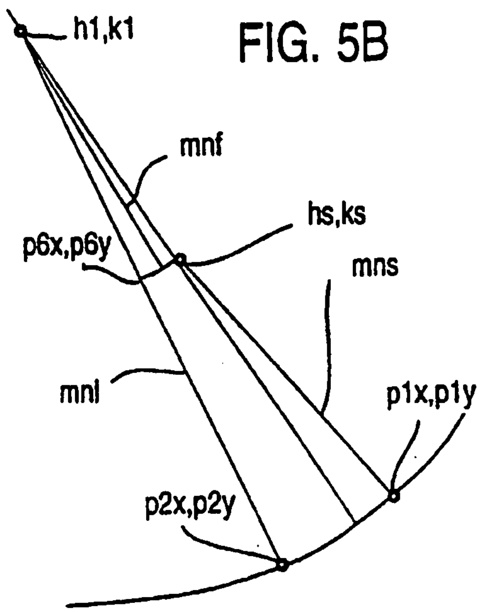



FIG. 5B

LARGE CIRCLE FIRST

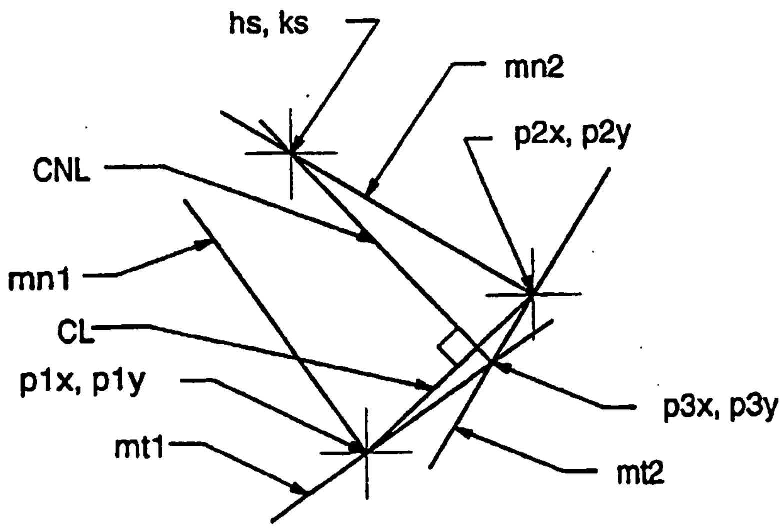
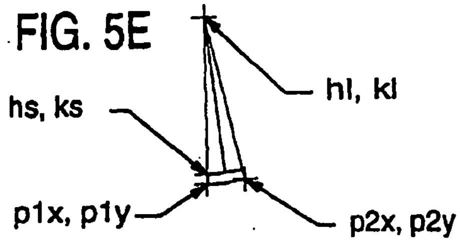


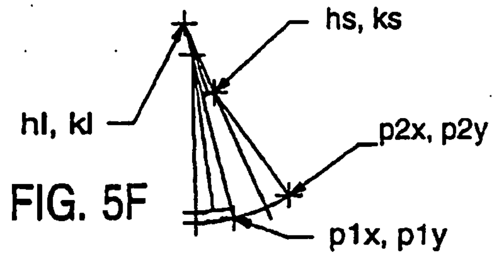

FIG. 5D

FIG. 5E



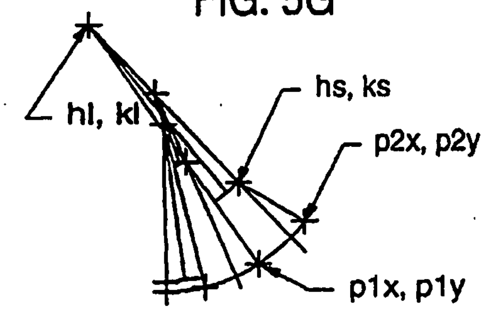

Spline Seg. No. 1
Circle Seg. Nos. 1 and 2

FIG. 5F



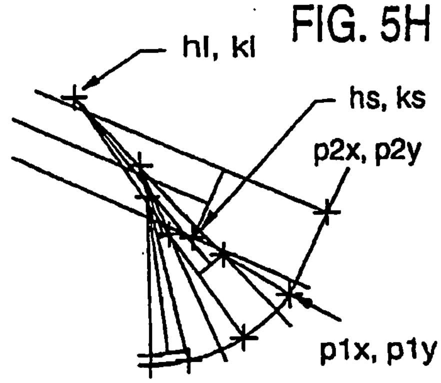

Spline Seg. No. 2
Circle Seg. Nos .3 and 4

FIG. 5G

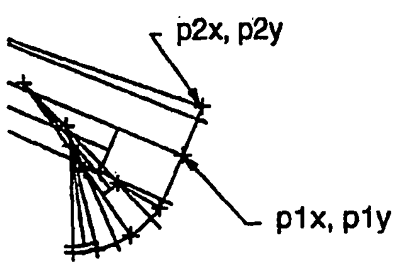



Spline Seg. No. 3
Circle Seg. Nos. 5 and 6

FIG. 5H

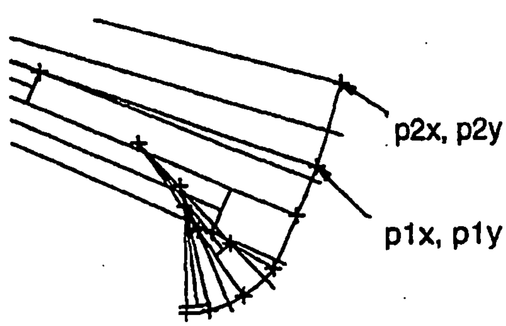



Spline Seg. No. 4
Circle Seg. Nos. 7 and 8




Spline Seg. No. 5
Circle Seg. Nos.9 and 10

FIG. 5I




Spline Seg. No. 6
Circle Seg. No.'s 11 and 12

FIG. 5J

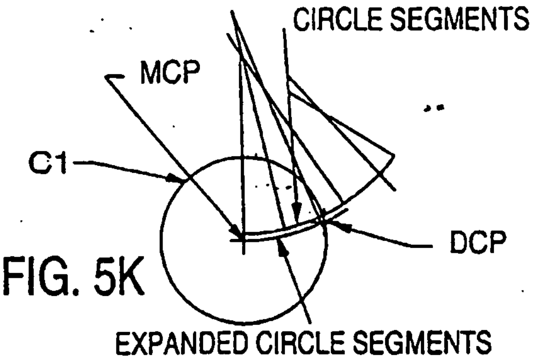



FIG. 5K

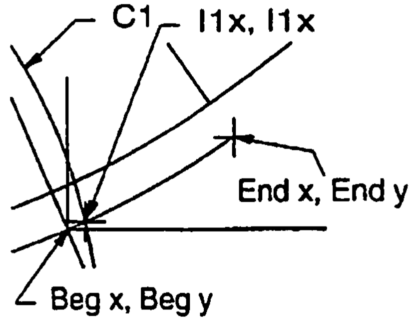



FIG. 5L

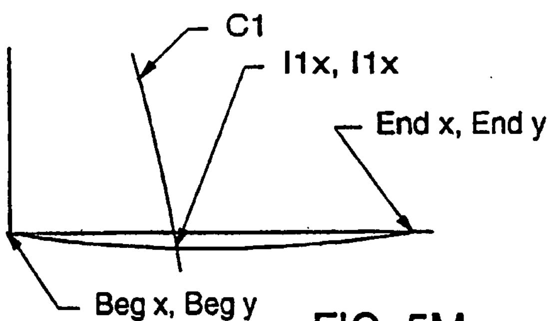



FIG. 5M

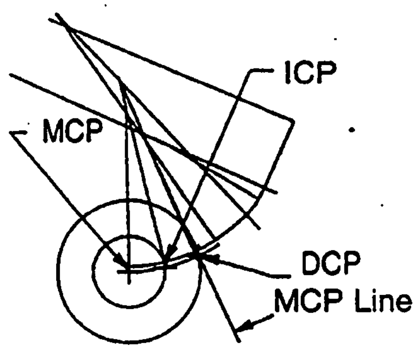



FIG. 5N

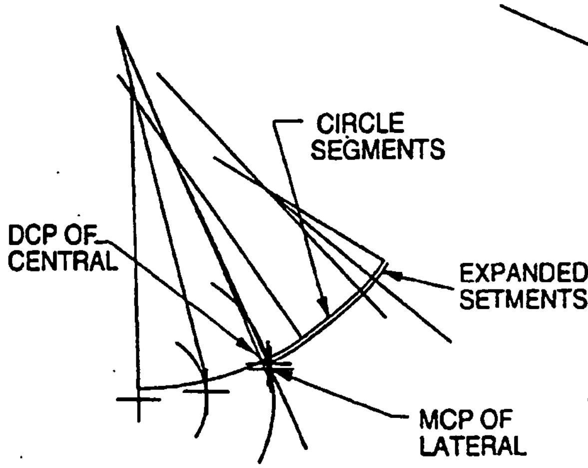



FIG. 5O

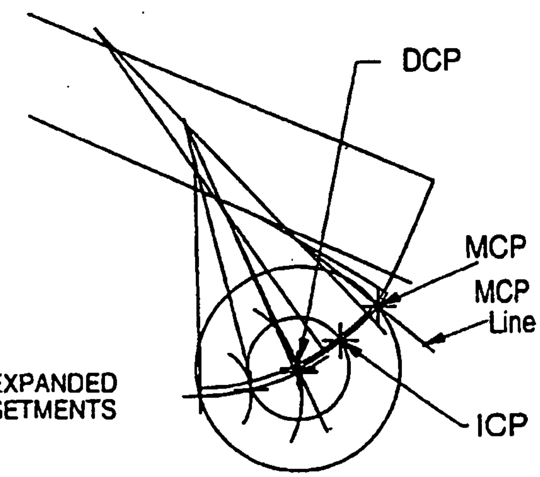



FIG. 5P

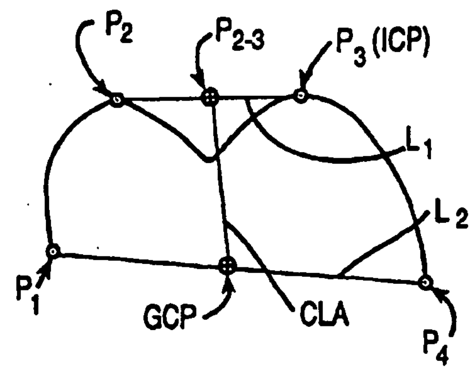



FIG. 6A

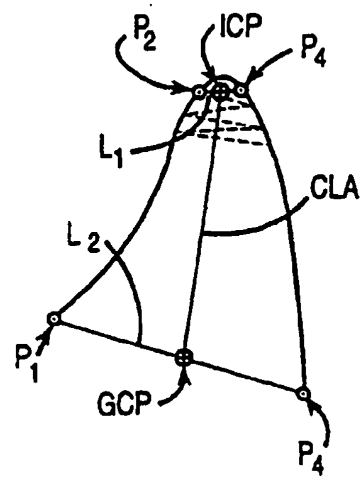



FIG. 6B

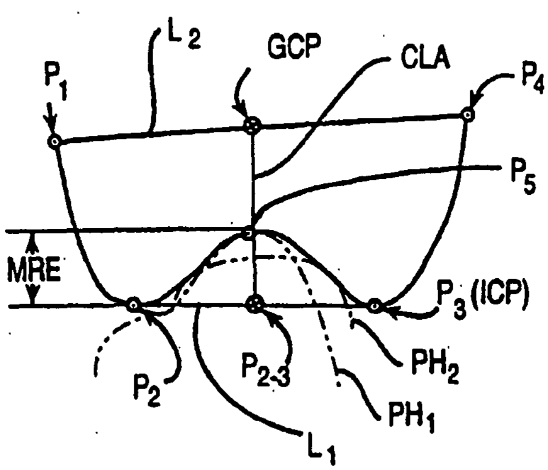



FIG. 6C

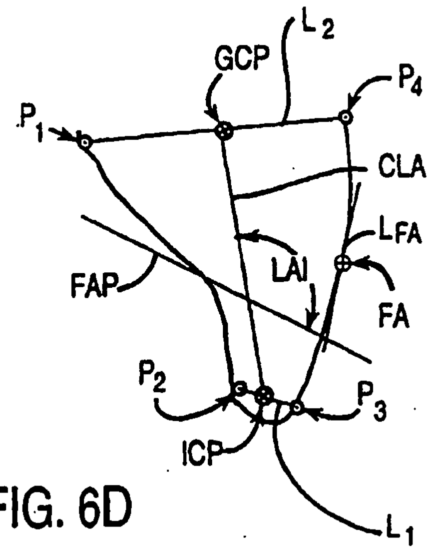



FIG. 6D

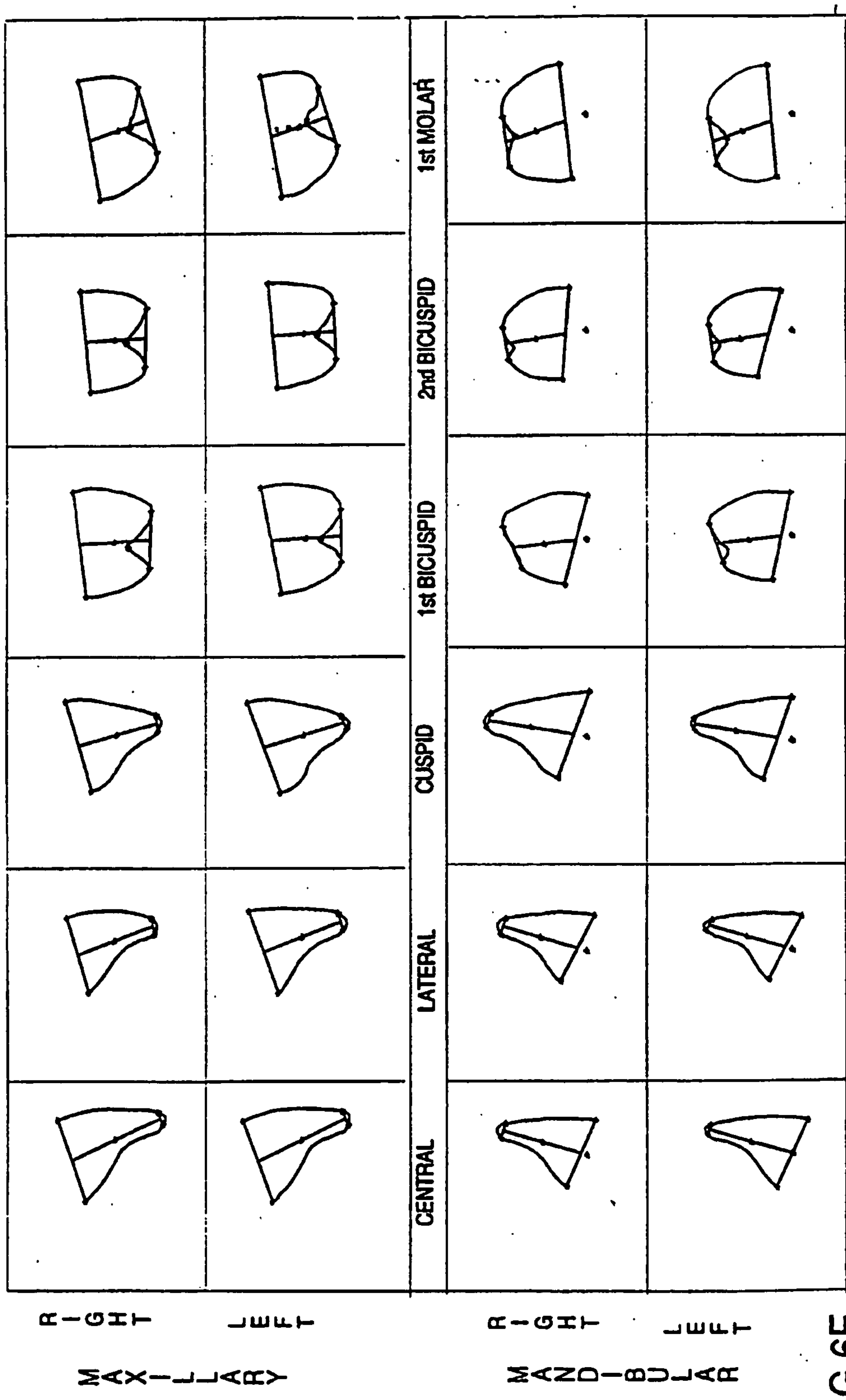

1st MOLAR
2nd BICUSPID
1st BICUSPID
CUSPID
LATERAL
CENTRAL
MAXILLARY
RIGHT
LEFT
MANDIBULAR
RIGHT
LEFT

FIG.6E

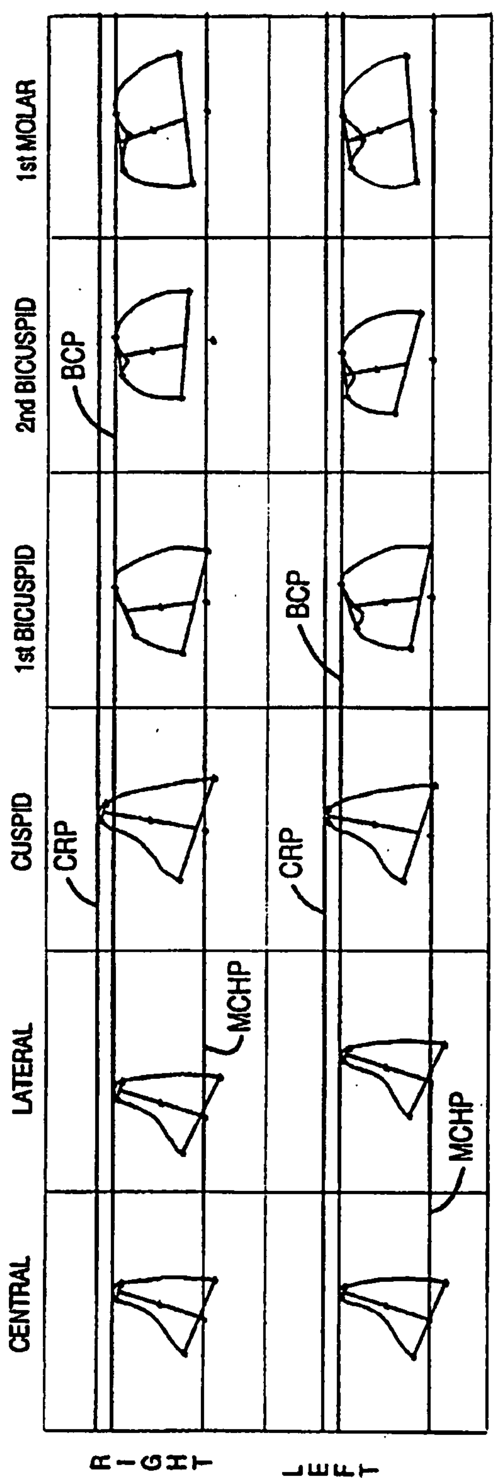



FIG. 6F

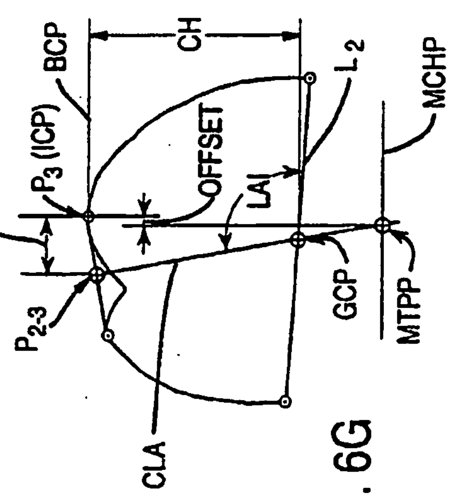



FIG. 6G

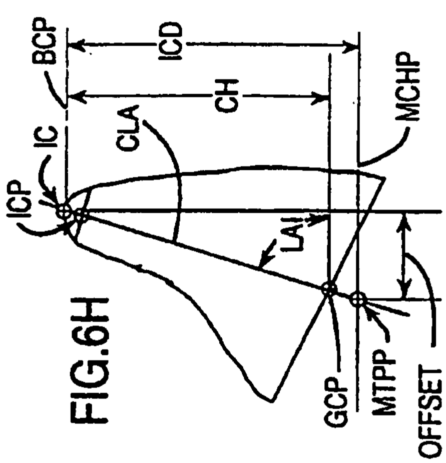



FIG.6H

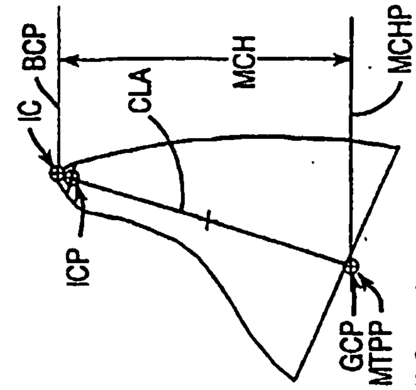



FIG. 6I

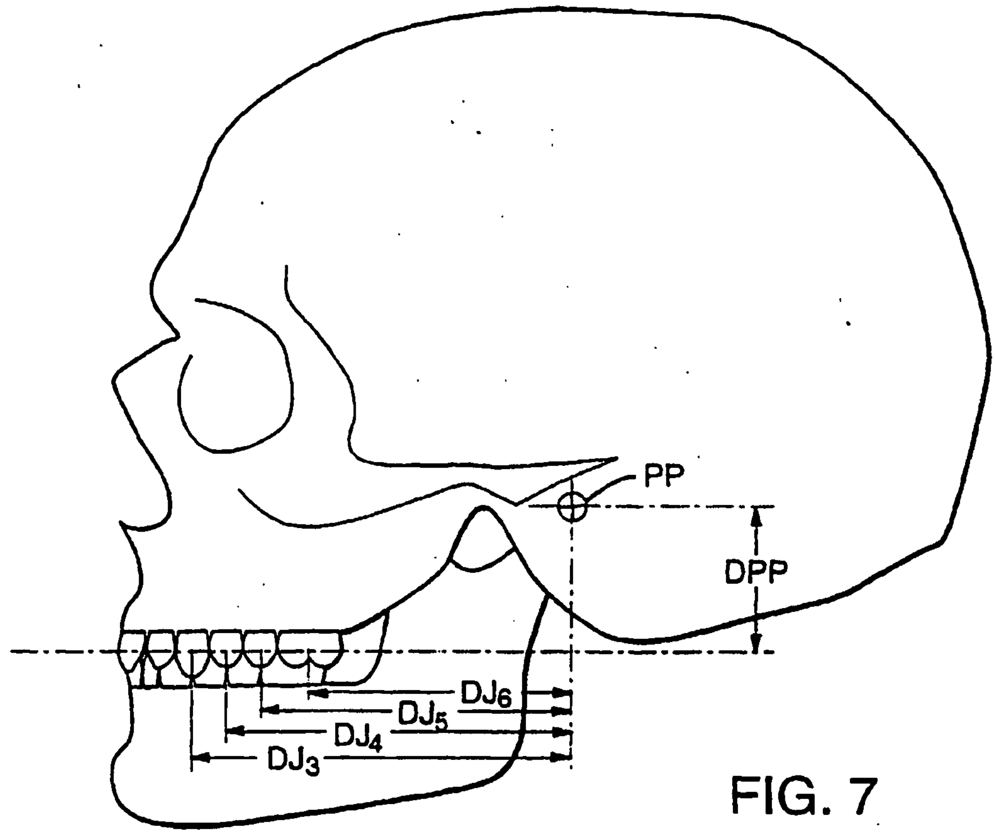



FIG. 7

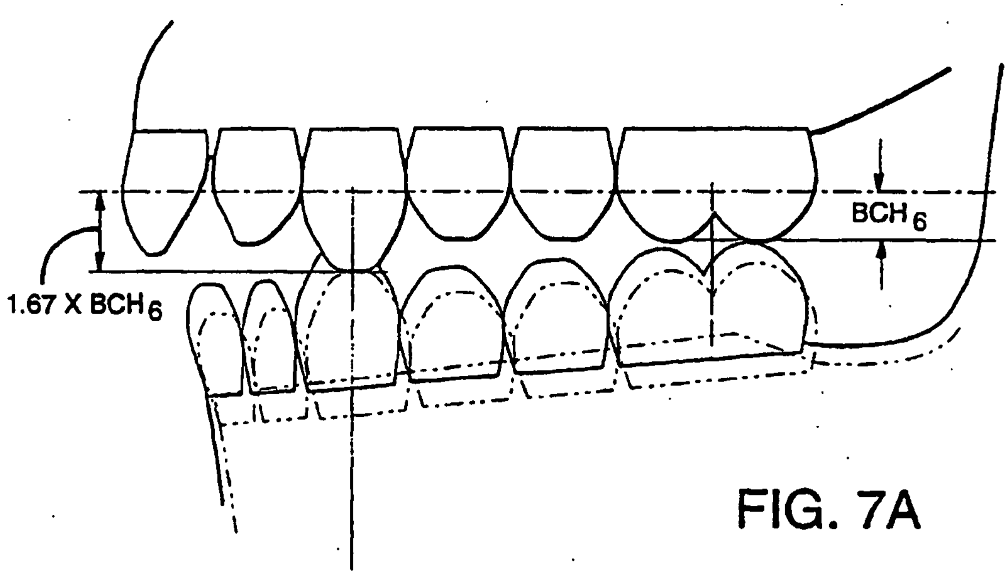
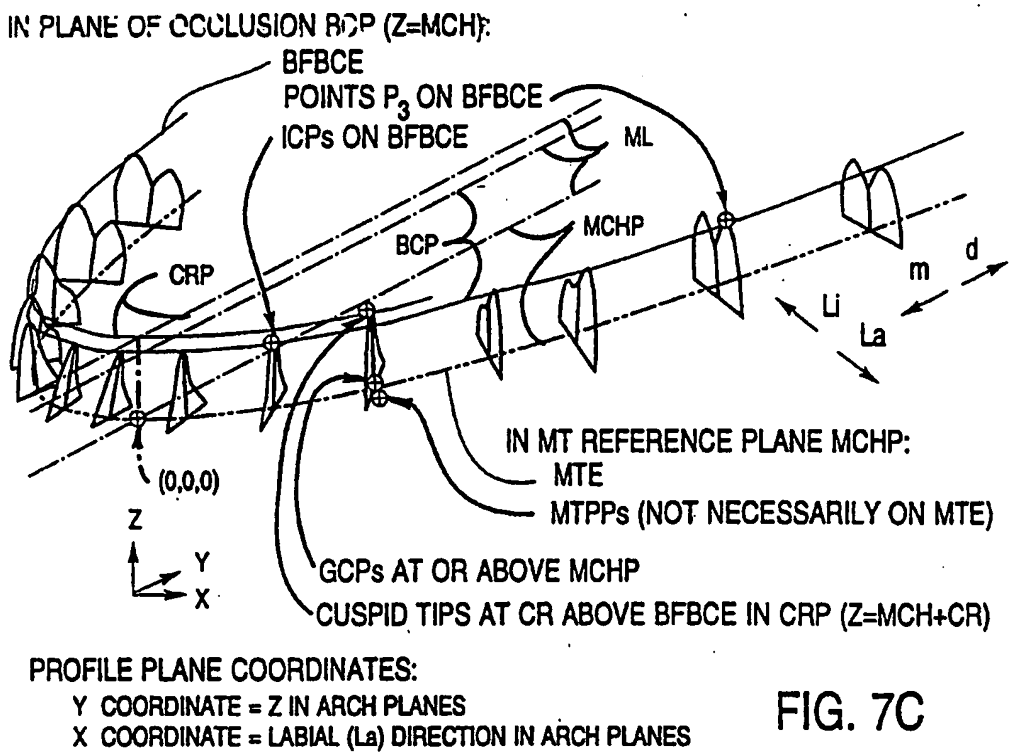
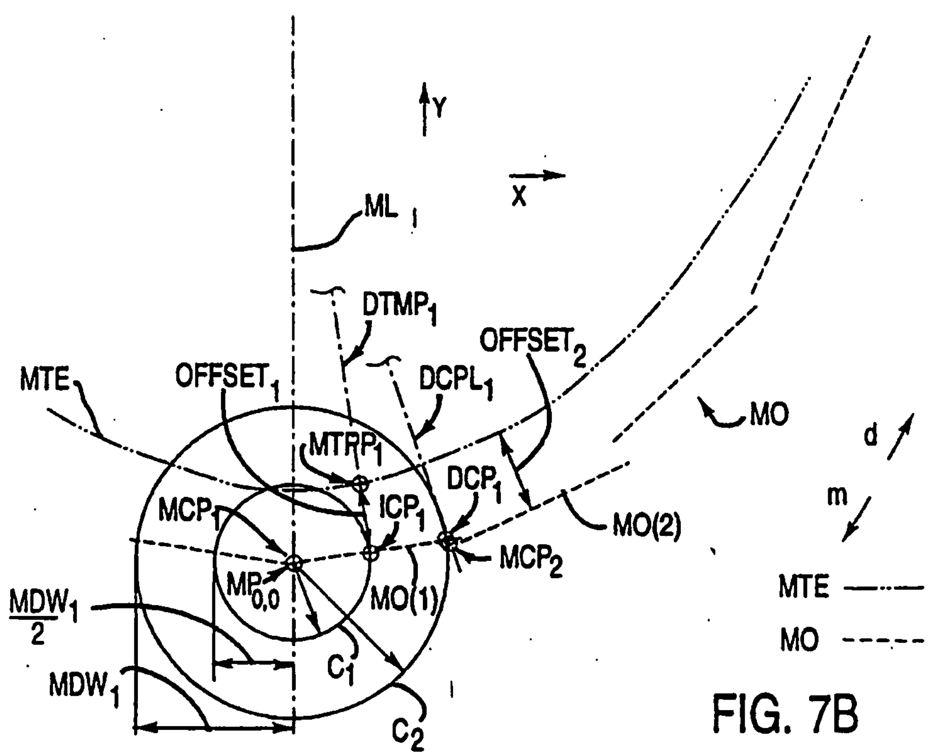



FIG. 7A



IN PLANE OF OCCLUSION BCP (Z=MCH):
BFBCE
POINTS P3 ON BFBCE
ICPs ON BFBCE
ML
MCHP
BCP
CRP
m
d
Li
La
IN MT REFERENCE PLANE MCHP:
MTE
MTPPs (NOT NECESSARILY ON MTE)
(0,0,0)
Z
Y
X
GCPs AT OR ABOVE MCHP
CUSPID TIPS AT CR ABOVE BFBCE IN CRP (Z=MCH+CR)
PROFILE PLANE COORDINATES:
Y COORDINATE = Z IN ARCH PLANES
X COORDINATE = LABIAL (La) DIRECTION IN ARCH PLANES


FIG. 7C



Y
X
ML
DTMP1
OFFSET2
MTE
OFFSET1
DCPL1
MO
d
MTRP1
DCP1
MCP1
ICP1
m
MO(2)
MCP2
MP0,0
MO(1)
MDW1/2
MTE
MO
C1
MDW1
C2


FIG. 7B

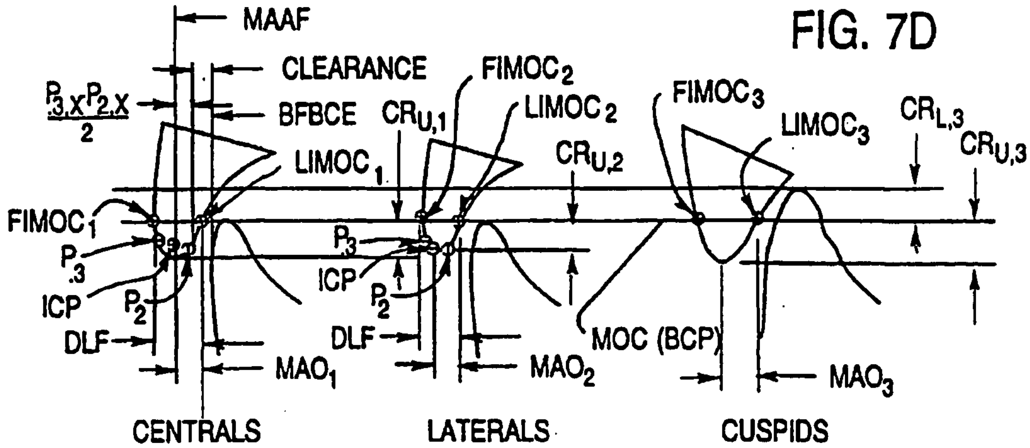
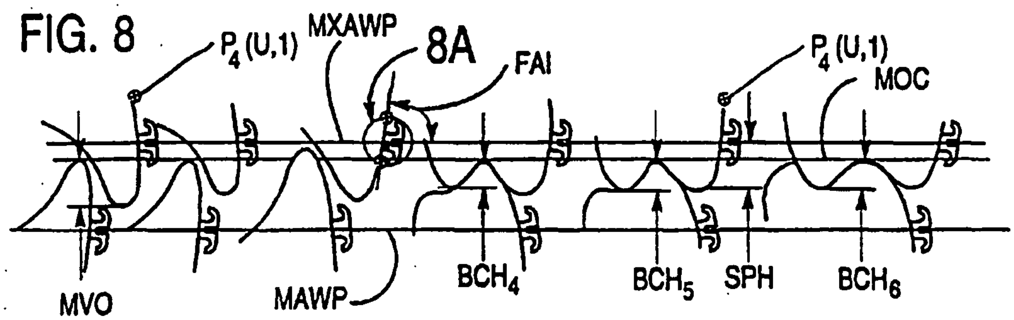



FIG. 7D

FIG. 8



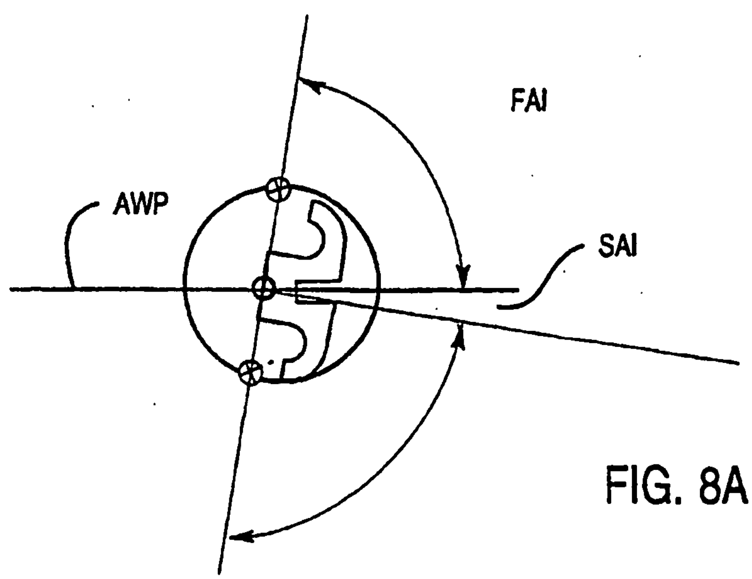




FIG. 8A

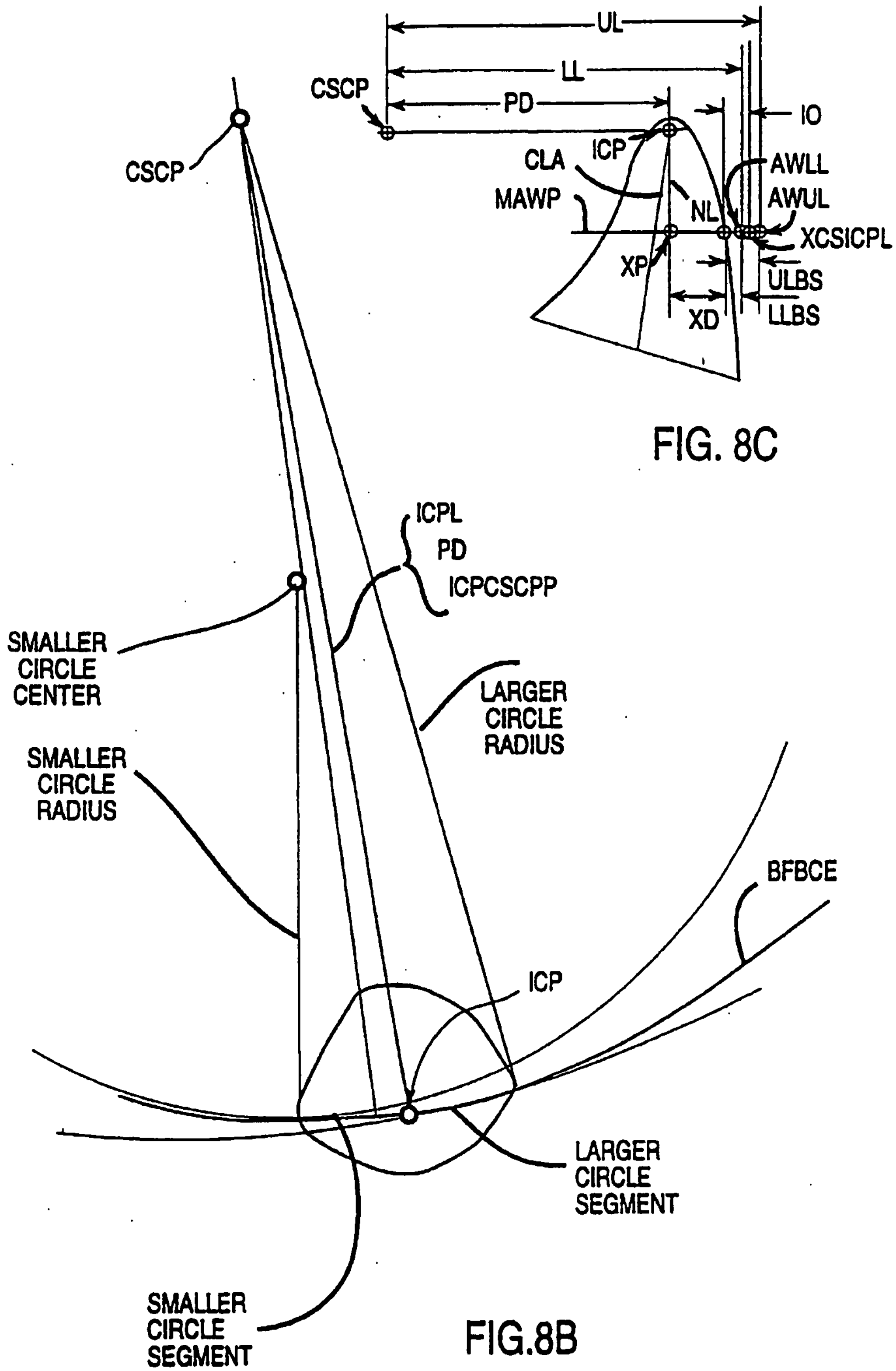
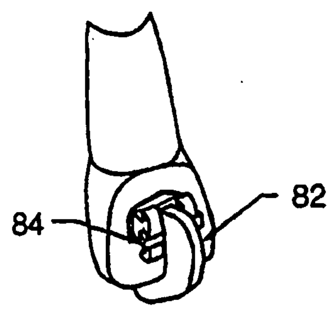

UL
LL
CSCP
PD
IO
ICP
CLA
AWLL
MAWP
NL
AWUL
XCSICPL
XP
ULBS
XD
LLBS
CSCP
ICPL
PD
ICPCSCPP
SMALLER CIRCLE CENTER
LARGER CIRCLE RADIUS
SMALLER CIRCLE RADIUS
BFBCE
ICP
LARGER CIRCLE SEGMENT
SMALLER CIRCLE SEGMENT

FIG. 8C

FIG.8B

FIG. 8D



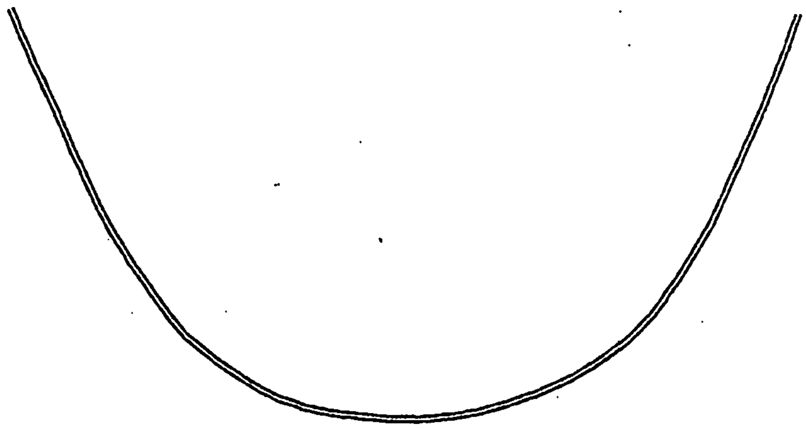



FIG. 8E

FIG. 8F

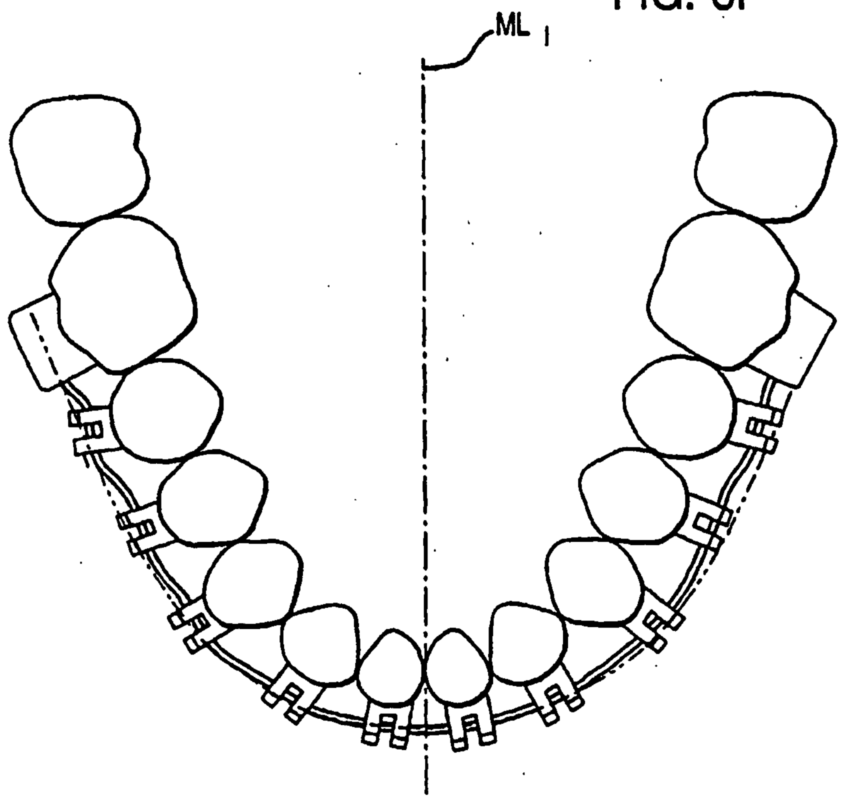
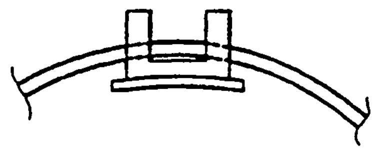


FIG. 8I



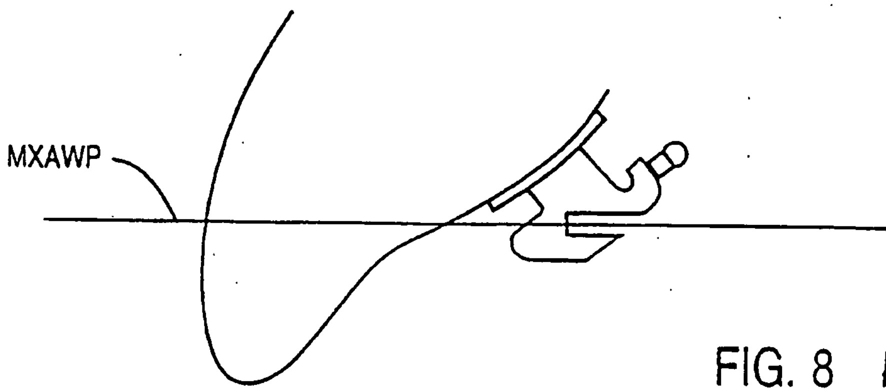



FIG. 8 H

FIG. 8 G

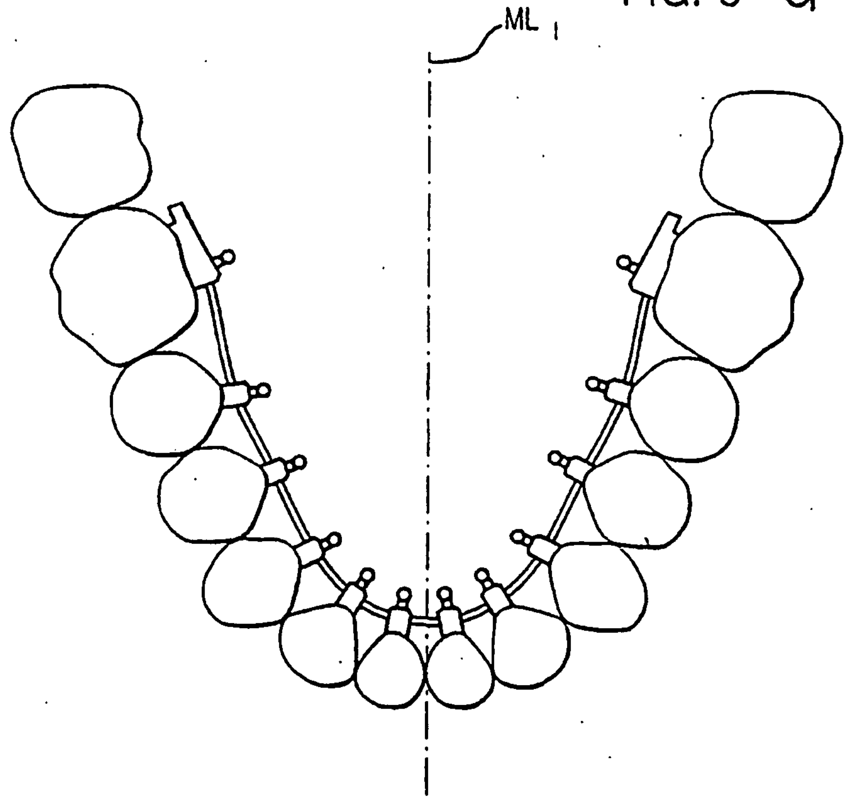
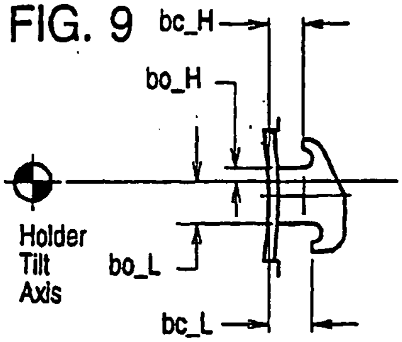


FIG. 9



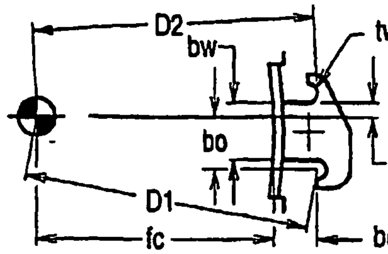




FIG. 9A

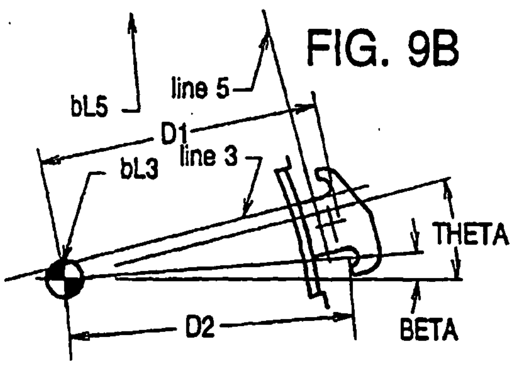



FIG. 9B

FIG. 9C

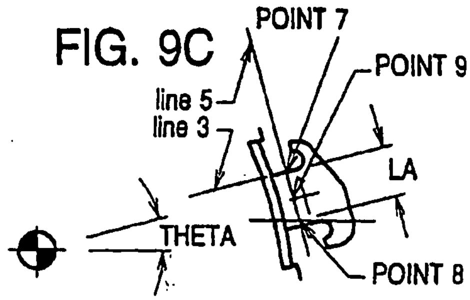



FIG. 9D

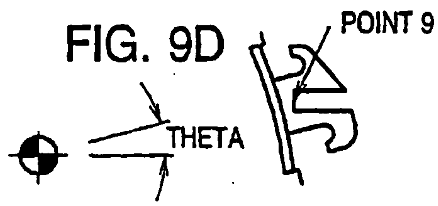



FIG. 9E

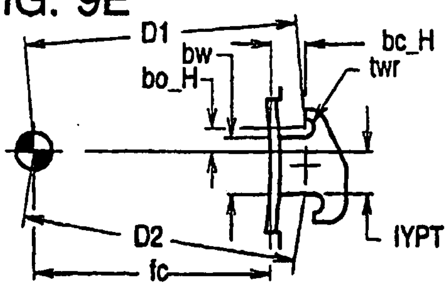
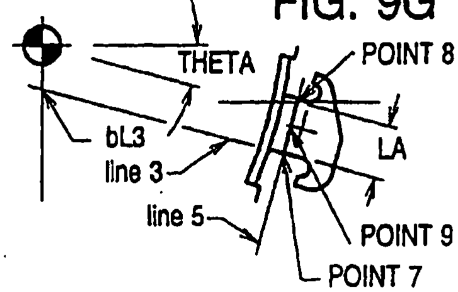



FIG. 9G



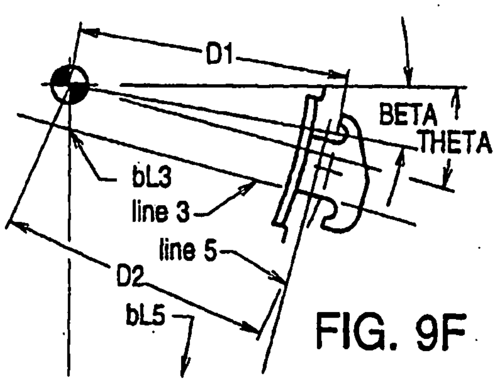




FIG. 9F

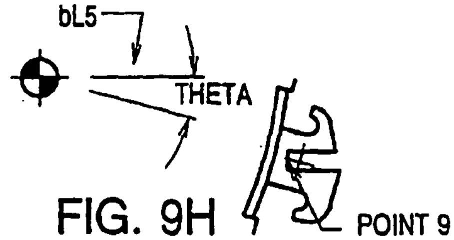



FIG. 9H

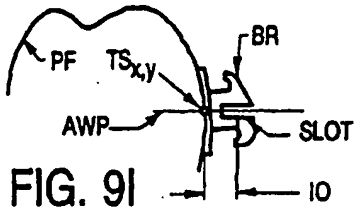



FIG. 9I

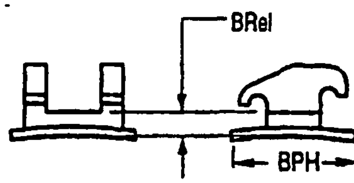



FIG. 9J

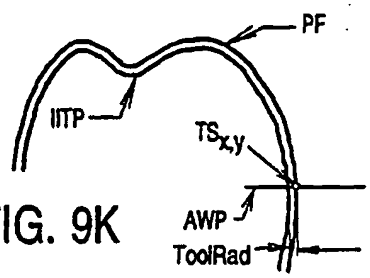



FIG. 9K

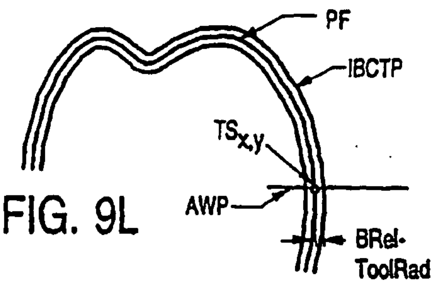



FIG. 9L

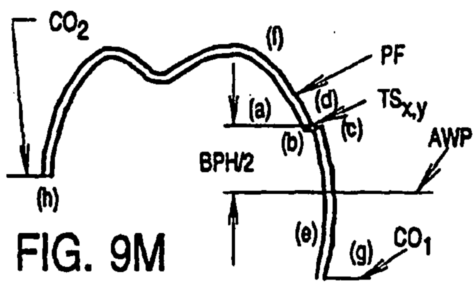



FIG. 9M

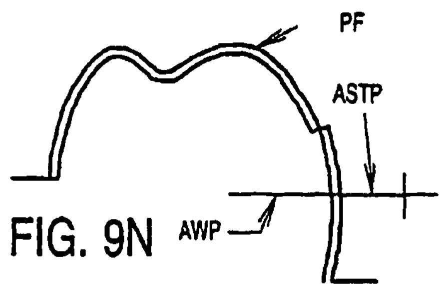



FIG. 9N

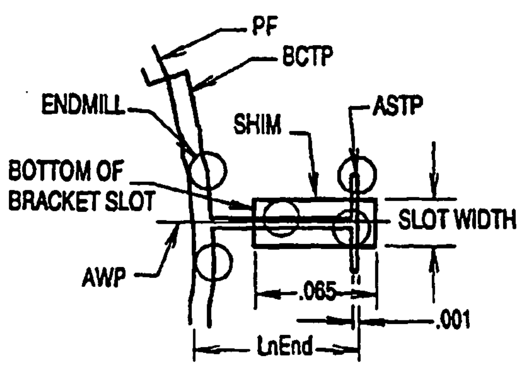
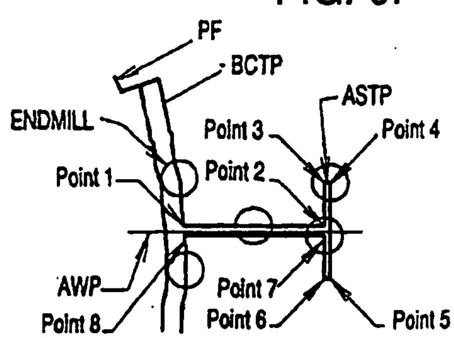



FIG. 9O

FIG. 9P



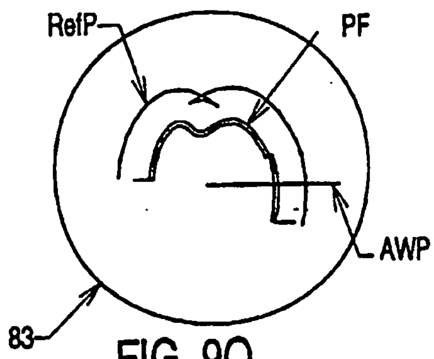
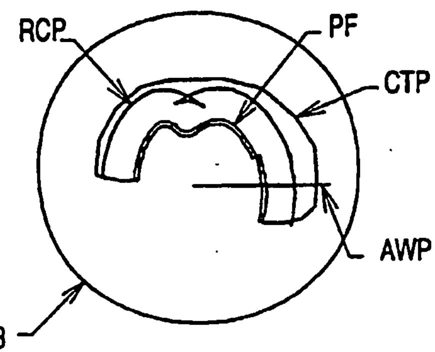



FIG. 9Q

FIG. 9R



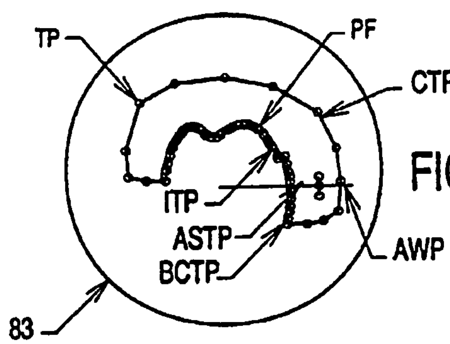
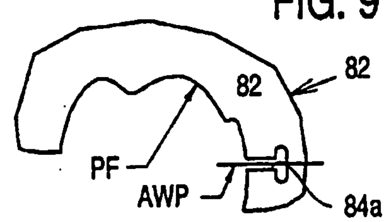




FIG. 9S

FIG. 9T



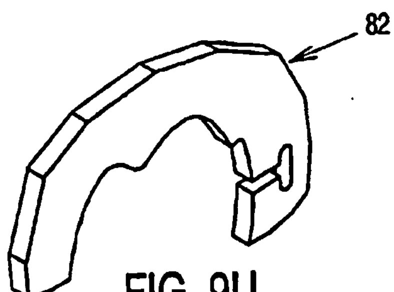




FIG. 9U

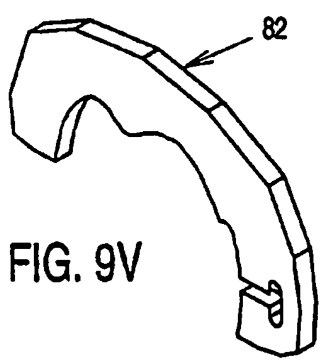



FIG. 9V

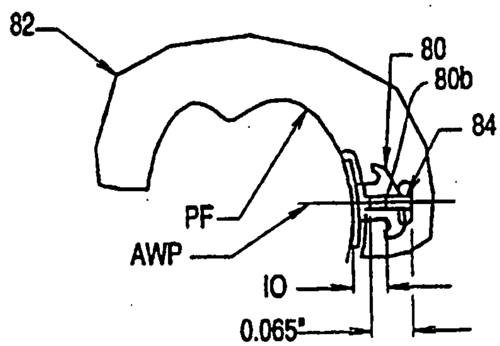



FIG. 9W